N INTRODUCTION TO THE STUDY OF BIOLOGY

BY

J. W. KIRKALDY

AND

I. M. DRUMMOND

Science Mistresses at the North London Collegiate School for Girls

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PREFACE

THIS book is an attempt to present to those beginning the study of Biology animals and plants as living organisms with many common characteristics: as springing from a common origin, and although following widely divergent lines of development, always exhibiting an essential similarity underlying diversity in the manifestation of the activities of life.

It is hoped that the book may prove useful to the upper forms of schools and to university students of the first year. The organisms dealt with are those prescribed in the syllabus of the Oxford and Cambridge Schools Examinations Board, with certain additions designed to bridge over the gulfs produced by too close an adherence to the 'type-system'. No doubt the fundamental problems of Biology are best appreciated by the careful investigation of a few selected individuals, but it is well to suggest the fact that no organism stands alone, that it is always one of a multitude of more or less closely similar forms.

The structure and life-histories of the organisms chosen here, their habits and the adaptations to their surroundings have been chiefly considered: details of Histology and Embryology have been regarded as out of place in a work of so introductory a character, and there was the less need for their inclusion as both subjects are fully discussed, for animals, in Professor Bourne's *Comparative Anatomy*; for plants, in Professor Scott's *Structural Botany*, to which books the more advanced student may be referred.

A word in explanation of the treatment of the vertebrates may be in place here. The frog, the type almost invariably

selected to illustrate vertebrate anatomy, has been dispossessed on account of its extreme specialization. The ancestral vertebrate was undoubtedly aquatic, and hence primitive characters are to be looked for among fishes, and especially in one so simple as the dogfish, which is, therefore, believed to be well fitted to afford a starting-point for the comprehension of the highest animals. The frog has, however, been retained to show the adjustment of an aquatic form to a terrestrial habit, since this is well displayed in its life-history. The introduction of some mammal was necessary in the last chapter on animals, as little is known of the physiology of vertebrates in general, and relatively much of mammals: the rabbit has been selected as a form easy to be obtained and of a convenient size.

Our thanks are due, and are most gratefully tendered, to Miss Violet Bonner and Miss Dora Lee who have made many of the diagrams; to Miss Dorothy Maude, M.P., for assistance in the preparation of Chapter XVII; to Miss Elsie Wakefield, who read for us several of the pages dealing with plants; to Professor Bourne for many helpful suggestions, and especially to Mr. Nagel, without whose timely advice the work would never have reached its present form.

J. W. K.
I. M. D.

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PART I. UNICELLULAR ORGANISMS

CHAPTER

AMOEBA

If specimens of water from ponds or ditches be examined under the microscope, they are seen to contain numbers of fragments of such various colours, sizes, and shapes, that it almost seems that no two are alike, or indeed resemble each other in any way After a few minutes of careful inspection, however, it will be noticed that, in spite of all the differences, some of the fragments agree in being quite still, or only swept about when the water on the slide is disturbed, while others can move 'of themselves' as we should say, even if it is only to give an occasional little wriggle Again, the motionless particles have often no particular form there may indeed be little bits of stick, or grains of sand, but many are just tiny masses of decaying matter The moving bodies, however, are of characteristic shapes, and seem better worth examining. The particles which are only swept about by currents in the water are, in fact, inanimate or not living, while the others which move 'of themselves' are living bodies or organisms Besides this power of movement, the living bodies, contrasted with inanimate particles, exhibit other and more important differences, which will perhaps be best understood if we study one of them in detail, in preference to talking generally about all. The Amoeba, a form which occurs in water taken from near the bottom of ponds and ditches, is very convenient for this purpose, both because it is easily found and also because it is of very simple structure.

The Amoeba (Fig. 1) is a tiny irregular mass of a semi-fluid substance, transparent and colourless, or of a greyish tinge. Its outline, always irregular, undergoes constant change, owing to the appearance of outpushings of the

body-substance, which are protruded at one moment, but soon may have disappeared into the general mass of the body. A shock, such as a sharp tap on the glass slide, or a touch upon the Amoeba itself, causes the outpushing to disappear instantly into the general mass of the body, and gives an illustration of what is perhaps the most characteristic property of living substance, its irritability, or power of response to stimulus The protrusions of the

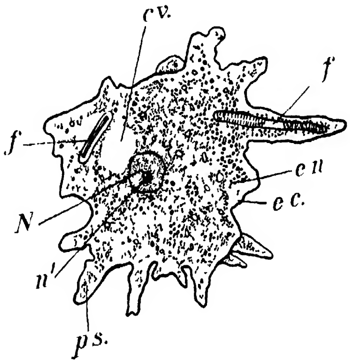


FIG 1 Amoeba

c v contractile vacuole.
f. food vacuole
ec. ectosarc
en endosarc
N nucleus
n' nucleolus
ps. pseudopodium

body cause the Amoeba to get bigger on one side, but this involves its getting smaller on another, or in other words, a withdrawal of substance from another side, and so the organism moves along, really changes its position, by slipping over the slide in the direction towards which the outpushings point

The Amoeba also feeds: it ingests or takes into itself other organisms tinier than itself, and is able, after digesting its prey, to make from this new particles of its own body-substance, so that it becomes larger by actual

increase of its own material thus it has the power of growth. Growth such as this must be carefully distinguished from 'growth by accretion' such as occurs in inanimate bodies, for instance in crystals In that case particles of the inanimate substance are, without undergoing any change, simply set upon the outside of the original crystal in layers, and, while they make it larger, do not affect the relations of the particles already in position. Growth by accretion may occur in organisms, as will be seen later; but real growth, which consists in the actual manufacture of living from not-living material, is characteristic only of life The substance which makes up the body of the Amoeba is peculiar to it but all organisms consist essentially of the same kind of living material, which is known as protoplasm, a name first used in this wide sense by Max Schultze, a German biologist Exactly what protoplasm is we do not know any detailed examination of its nature kills it at once, and when it is killed, it is of course not-living matter The particular not-living matter which we obtain by killing protoplasm consists principally of proteins, substances of great chemical complexity, which decompose readily into simpler substances, such as water, ammonia, hydrogen sulphide, carbon dioxide, and in a final analysis give oxygen, hydrogen, nitrogen, carbon, sulphur, with small and varying proportions of certain other elements. Given, however, all these elements, or even already elaborated proteins, all attempts at making protoplasm have hitherto failed We do not know what life is we can only say with Huxley that protoplasm is the 'physical basis of life'

When, by growing, by the formation of new protoplasm, the Amoeba has attained a certain size, it divides into two parts, each of which is exactly like the original form, so that there are now two organisms instead of one this process is called reproduction. Every organism of whatever size, or kind, always presents the properties of irritability, movement, feeding, growth, reproduction, which are thus the great manifestations of life, and serve to distinguish living from not-living bodies.

The Amoeba, then, is alive, it is, in fact, an example of the simplest form of life, for its grey body is just a lump of protoplasm. At first sight it seems to be the same all

the way through, but to a closer inspection it presents a covering layer of clear colourless material (possibly the more liquid part of the protoplasm which has run to the surface), the ectosarc, and a central mass, the endosarc, containing granules which give the body its greyish tinge. These granules tend to be in constant motion, for the protoplasm streams in various directions, and the granules are carried along by it The streaming can be seen most easily in the formation of the outpushings, which serve as locomotor organs, and are therefore called pseudopodia, or false feet When a pseudopodium is being formed, the clear ectosarc flows out first to make a tiny hump; then the endosarc is seen, by the movement of the granules, to run into the hump, and seems to push it out further and further, often to such an extent that the greater part of the body becomes pseudopodium, the granules running outwards into the process all the time.

The granules are partly stored-up food, partly little collections of waste matter sometimes tiny fat droplets may be seen among them, and these are also food stores. Towards the middle of the endosarc is a rather large rounded body, called the nucleus, best seen in a specimen which has been treated with some stain such as methyl green. The stain is dropped upon the slide, or allowed to run under the cover-slip, and while the whole organism may be faintly dyed, the nucleus, because of a difference in its chemical composition, takes up much more of the colouring matter than does the rest of the body, and shows out very distinctly. It is separated from the general mass of the protoplasm by a delicate membrane, and is denser than the rest of the body. It is really the most important part of the organism for it governs all the activities—feeding, growth, reproduction. Within the nucleus, yet denser and more deeply staining masses, the nucleoli, may be found Besides solid bodies, definite spaces or vacuoles occur in the endosarc. Some of them contain the tinier organisms, which have been ingested as food. The food is taken in by the pseudopodia; when a hungry Amoeba comes in contact with a suitable organism, two pseudopodia arise on the side next it and grow out so as to surround it on all sides. They grow so far towards each other that at last they meet and then coalesce com-

pletely, enclosing a small space or vacuole in which lies the food particle in a droplet of water. The food particle in its solid state is of no use to the organism the nutritive parts must be broken down and dissolved before they can be absorbed by the protoplasm and be made into its substance. This preparation of the food, rendering it fit for use, is called digestion, and digestion in the Amoeba is effected by special liquids made by the protoplasm and passed into the vacuole to come into contact with the prey. The nutritive solution is absorbed by the protoplasm, so that the vacuole shrinks round the solid indigestible parts of the food until they just lie in the endosarc Finally they are left behind, as the Amoeba flows on by the protrusion of new pseudopodia, and so food vacuoles vary in size and number according as the organism has fed lately or a long time ago. The food goes to form new particles of protoplasm, or nutritive stores to be associated with the living substance, all the new particles being deposited among the old ones

The food vacuoles may always be recognized by the presence of food material in some stage of digestion, but another sort of vacuole is present, lying at the border of the endosarc and containing only liquid it disappears at intervals, always reappearing again after a short time. This is the contractile vacuole, which receives certain waste products from the body substance As the waste liquid accumulates, the vacuole increases in size until a limit is reached and the walls shrink together, squeezing out the contents Exactly how it escapes is not known, as no pore or break in the ectosarc has yet been seen, but after the vacuole has vanished there is a pause, and then it begins to form again, at first as a tiny speck which gradually expands to the full size, and then disappears again The waste matters, or excretory products, as they are called, which are thus removed from the body, arise from the breaking down of the food reserves, or of the protoplasm itself. In moving, growing, or reproducing, the Amoeba uses up energy; and this is obtained at the expense of its food stores, or even of its own living substance. The molecule of the protein matter to which protoplasm is reduced when it is killed is of extreme complexity, so that a large amount of energy is involved in its formation. The

sum of the energy necessary for making the molecules of water, ammonia, and carbon dioxide is very much less than that needed for the production of the protein molecule; so that when the protein decomposes into the simpler compounds, as it does very readily, a certain amount of energy is liberated for the living work of the organism. The decomposition of organic substance is a form of oxidation, or of the combination of some other elements with oxygen, just like what takes place when carbon and oxygen unite in the burning of coal, or of a candle; so all living bodies[1] must be provided with supplies of free oxygen. The Amoeba obtains its oxygen from that which is dissolved in the water in which it lives, and takes it in by every part of its surface, at the same time giving out carbon dioxide by a process of gaseous diffusion, and nitrogenous waste in the form of a liquid The process of casting out such products, which is very characteristic of protoplasm, is known as excretion, the exchange of gases being termed respiration We can see now that important chemical changes are continually taking place in protoplasm food is absorbed, digested, and manufactured either into new protoplasm, or into food stores associated with the protoplasm these stores, and occasionally the protoplasm itself, are oxidized and broken into simpler compounds which are got rid of, or excreted The whole cycle of changes is known as metabolism. In the Amoeba, food is obtained in the solid form by the coalescence round it of two pseudopodia. Excretion of waste products is effected, as regards nitrogenous waste by the contractile vacuole, and in respect of carbonaceous waste partly by the vacuole and partly by the general surface of the body, which also serves for the absorption of oxygen, and thus as a respiratory organ

So long as the intake of food balances the output of excreted material, the bulk of the organism must remain constant. When the intake is greater than the output, and the formation of new material exceeds the decomposition of the old, the organism must grow There seems to be a limit to the growth of any given organism, and when this limit is reached there must be some other

[1] There are certain organisms which can get energy by other means, but these cannot be dealt with here

fate for the surplus protoplasm We find that it goes to form a new individual, or, in other words, that reproduction takes place. Reproduction in the Amoeba is very simple; a single individual divides into two equal parts. The nucleus first becomes elongate and somewhat dumbbell-shaped, then a constriction appears in the body. The nucleus divides completely into two parts, and this is followed by the division of the entire organism into two new ones. The two new Amoebae are, so far as is known, identical, and it is thus quite impossible to speak of either parent or offspring: we can only say that where there was one individual there are two.

While the Amoeba usually leads an active life, occasionally it undergoes a resting period. It withdraws its pseudopodia and becomes spherical, and the external layer of the protoplasm is hardened to form a protecting coat. Many new nuclei are formed by division of the old one, and the protoplasm collects round these to make as many small corpuscles, or spores, as there are nuclei After a time the coat bursts, the spores are set free, and begin life as small Amoebae, except in point of size exactly like that from which they arose. At other times the quiescent, or encysted, period does not lead to a reproductive process: the Amoeba simply rests for a while, then loses its spherical form, protrudes pseudopodia, and resumes its active life.

CHAPTER II

SACCHAROMYCES

SACCHAROMYCES is a tiny organism well known in masses as 'yeast': 'brewers' yeast', a brownish-grey, frothing liquid, obtained from any brewery, and 'German yeast', a putty-like mass, to be bought from the baker. The household use of yeast is for making bread, for causing the 'rising' (fermenting) of dough, i.e for turning a close, heavy lump of flour and water into a light, spongy mass, which needs only baking to be the best sort of bread. Yeast is also the cause of the 'fermentation' of beer, or wine, and as single yeast bodies in a dry state are always present in ordinary air, they sometimes make themselves felt unpleasantly by settling in sugary substances, for instance, in jam which has been insufficiently boiled or kept in a warm, damp place, and causing them to ferment. German yeast is made from brewers' yeast by partial drying, and can be readily returned to its original condition by mixing with sugar and water and putting near the fire. There is always a thick sediment at the bottom of the liquid, and, if some of this be examined under the microscope, numbers of the minute organisms may be seen

Each little body is incapable of locomotion. it consists of a mass of protoplasm surrounded by a firm coat, and containing a nucleus. The coat does not consist of protoplasm; it is made by the protoplasm from its food stores, and is composed of cellulose, a carbohydrate closely allied to starch Cellulose is not living substance, but is merely secreted by protoplasm as an external coat. It is not necessarily formed in connexion with already existing cellulose, it will be seen to arise upon naked protoplasm when the reproductive processes of yeast are studied.

Since it is not alive, the coat has no power of feeding, or growing, or reproducing it does, however, increase both in surface and in thickness; but this is simply a process of

accretion (see p. 3) and is entirely dependent upon the activity of the protoplasm. Vacuoles are present, but they are unlike those of Amoeba: they are not contractile and they do not contain food particles. They do not occur in very small individuals, but may increase in size and in number as the yeast bodies grow. It seems that their presence is caused by the growth of the wall which, as it is secreted by the protoplasm, is apt, if food be not very plentiful, to be formed from the protoplasm itself, or at least to cause a shrinkage in that substance by the

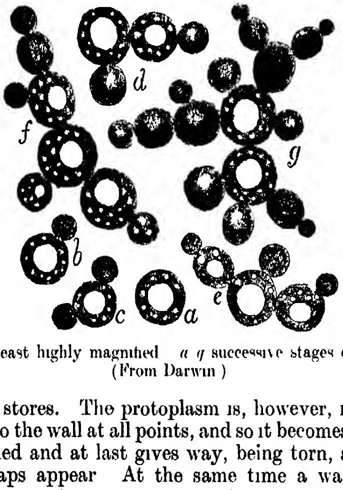


FIG. 2 Yeast highly magnified *a*–*g* successive stages of budding (From Darwin)

loss of its stores. The protoplasm is, however, necessarily attached to the wall at all points, and so it becomes stretched and strained and at last gives way, being torn, as it were, so that gaps appear At the same time a watery fluid, the cell sap, containing various matters, waste or reserve, in solution, is collecting in droplets, and this fills up the vacuoles as they are formed. Because of its unbroken coat, Saccharomyces cannot possibly feed as Amoeba does, by the ingestion of solid particles: the food must be fluid; it must be obtained from the fluid in which the organism lives; and it must be absorbed through the body-wall. This absorption takes place by a process known as osmosis. It is well known that if a salt solution be placed

in a glass tube, closed at one end by a membrane, such as a bladder or a piece of parchment, and the whole be allowed to dip into a beaker of pure water, an exchange will go on between the two liquids, pure water entering the tube through the bladder (as is shown by the rise in the level of the liquid in the tube), and the salt solution issuing more slowly from the tube into the beaker, until the two liquids become, both of them, solutions of the salt of equal strength. Some solutions pass more readily through membranes than others; and membranes may be prepared which exert a discriminating action, and permit the passage of only certain dissolved substances. In natural conditions, protoplasm constitutes one of these selecting membranes it allows the entrance, or exit, by osmosis, of some substances far more readily than others, while the cellulose wall is much more generally permeable (that is, more easily penetrated). This is seen in staining living organisms, or parts of organisms, for examination with the microscope; for many stains, which will easily get through a wall, will not dye the protoplasm so long as it is alive. The great importance of osmosis in the life of higher organisms will be referred to later on; at present it is clear that this is the only way in which yeast can obtain food. Everything necessary to build up new protoplasm is found in the grape-juice, or sprouting barley, in which the yeast naturally lives, and the organism not only grows, but also reproduces freely in such a substance

The reproduction of Saccharomyces is as simple as that of Amoeba one individual divides into two (with division of the nucleus); but the parts are not equal (Fig 2); the new body, or bud, is always much the smaller. The process, therefore, is known as budding, or gemmation; and it is the evidence of life first noticed in a microscopic examination Sometimes the buds do not separate from the parent, but still remain attached in this position they grow and even reproduce, so that in some cases long strings, or even branching clusters, are formed If food becomes scarce, another mode of reproduction may occur The protoplasm gathers towards the middle of the body, and as the nucleus divides into four, itself breaks up also into four parts, one to surround each of the new nuclei. The four new corpuscles arrange themselves in a pyramid, three below,

one above. Each is originally naked, but at once secretes a new cellulose coat (cf p. 8), and is known as a spore. The spores are set free by the bursting of the original wall. They are able to withstand extremes of drought and temperature for a considerable time, and then, if again carried into favourable conditions, to develop in the usual way.

We must now turn to a study of the changes which the presence of Saccharomyces brings about in liquids containing sugar. If a flask containing a dilute solution of sugar, in which a small bit of German yeast has been placed, is put near the fire, the liquid soon becomes turbid and a thick froth appears in patches on its surface. After a time it acquires a winey taste and smell, and lime water introduced into the neck of the flask turns milky at once, indicating the presence of carbon dioxide A further investigation discloses that sugar is gradually disappearing, while an increased amount of alcohol is produced, and carbon dioxide is being given off in quantities far larger than can be accounted for by ordinary respiration Yeast needs as food already prepared organic substances some of the sugar which disappears (about 5 per cent) is used as food, and to the rest (or 95 per cent.), the amounts of alcohol and carbon dioxide produced bear a definite relation; they are indeed its chemical equivalents, according to the equation —

$$C_6H_{12}O_6 = 2C_2H_6O + 2CO_2.$$

It seems that yeast flourishes only in a temperature higher than that of ordinary air, and the oxidation processes which result from respiration do not supply sufficient energy to give this heat. The energy, however, set free by the decomposition of the molecule of sugar into the simpler molecules of alcohol and carbon dioxide makes good the deficiency Proof of this is given by the fact that if deprived of oxygen the cells begin to be asphyxiated, and then they attack the sugar much more vigorously. A change of this kind, where complex organic material is decomposed by a definite substance produced by the activity of protoplasm, is known as 'fermentation', and the definite substance is called a ferment. The ferment is peculiar in being itself unaltered, although it can cause in other substances such great changes as that just described.

The ferment would thus seem capable of continuing to cause fermentation indefinitely; it is found, however, that unless the products of the process be removed, the activity of the ferment ceases. For example, yeast can go on turning sugar into alcohol, if the alcohol be taken away as it is formed; but if it be allowed to remain, the yeast gradually loses its activity; it seems to be choked, as it were, by the products of its own industry.

Fermentation is of many kinds and of common occurrence. It is probable that the digestion of protein matter by the Amoeba is effected by a ferment: it is certain that digestion in the higher animals is brought about by such means. In these cases the ferment is evidently a secretion of the protoplasm, in the one case of the entire organism, in the other of that of a special digestive tract. Until lately a sharp distinction was drawn between such 'unorganized ferments' and yeast and its allies, which were termed 'organized ferments', because their presence as living organisms was believed to be absolutely necessary for the operation to take place, in fact the living organism was believed to be the ferment. Recently, however, a German investigator, Professor Buchner, made careful experiments upon yeast, in which every possibility of the protoplasm's being still alive was excluded, and he was able to isolate an extract called 'zymase', which will bring about alcoholic fermentation in the entire absence of living cells. Thus the distinction breaks down, and the action of the zymase of yeast is strictly analogous to that which takes place in the processes of digestion in any animal.

CHAPTER III

SPHAERELLA

In wet weather, the rain which falls on heavy soils, such as clay, does not trickle away at once, but collects in any little crack or depression in the ground, forming puddles and larger and smaller pools. Sometimes such puddles acquire a green tinge, and this is due to the presence of numbers of minute organisms, themselves coloured green, called Sphaerella (Fig. 3 A). Under the microscope Sphaerella is seen to be of a roundish oval shape, with a fixed outline, and with two long whip-like processes attached to one end. It is rather difficult to watch, for it swims so rapidly that it is gone almost before there is time to focus it, and a little thin gum must be run under the cover-slip, or the tiny body must be entangled in the meshes of some cotton wool before it is still enough for study. When it swims about, the end which bears the whips goes first, so is called the anterior end. The whips or flagella are responsible for the rapid movements, for they are constantly lashing from side to side, and so drag the body through the water They may therefore be compared to the pseudopodia of Amoeba, and not only because they serve the same purpose of locomotor organs, but also because they are protrusions of the protoplasm; they may, in fact, be regarded as long, thin, fixed pseudopodia. As Sphaerella swims about it rotates continually on its long axis, so that it really describes a spiral course through the water The oval shape of the organism is maintained by a firm, colourless and tough coat, which stands away from the protoplasmic body, and is attached to it only by scattered strands or bridles like the wall of Saccharomyces, the coat consists of cellulose. The green hue is given by a colouring matter, chlorophyll, which is not diffused throughout the protoplasm, but is restricted to a special part of it, rather to the outside: this part

is called the chloroplast. It does not extend to the anterior end of the body, which is thus left colourless, and at intervals upon its surface are pyrenoids, tiny bosses of proteid matter covered by a thin layer of starch. Sphaerella possesses a nucleus, but neither food nor contractile vacuoles.

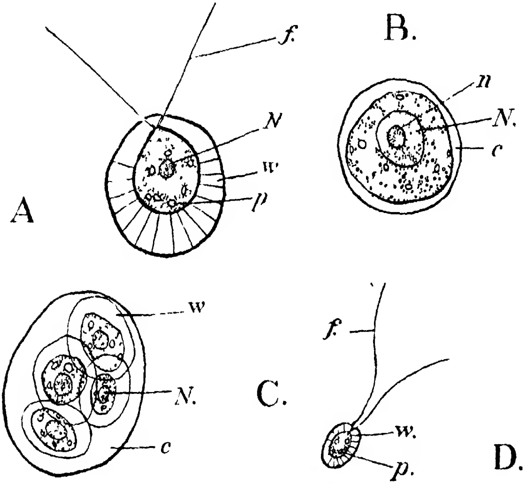


FIG 3 Sphaerella.

A. large motile form (after Hazen)
B the same encysted
C. cyst containing four spores.
D. small motile form
c. wall of cyst
f. flagellum.
N nucleus
n nucleolus
p. pyrenoid
w cellulose coat

Sphaerella is not always entirely green; there is often more or less admixture of red, which may even mask the green completely. The red tint is caused by another pigment, known as haematochrome. When the shallow pools in which the organism lives begin to dry up, it enters

upon a resting phase (Fig. 3 B). The flagella and bridles are lost, the cellulose coat thickens, and a red flush, gaining in intensity, begins to replace the green colour. There is usually, even in the active stage, a thin layer of haematochrome round the nucleus, and as the organism enters upon the quiescent period, this increases from within outwards, until the whole body looks red, although some chlorophyll always remains. By the time the pools are quite dry, they are found to be coated with a blood-red crust of resting Sphaerellae. The vitality of the body is now at its lowest, and the formation of the haematochrome seems to go with this, and to enable the enfeebled body to withstand the adverse conditions. Sphaerella may continue in this state for considerable periods of time; then it may undergo division into four, eight, or sixteen parts (Fig. 3 C), each new individual secreting a delicate wall, and forming a pair of flagella (Fig. 3 D), before escaping from the parent coat. Water accumulates immediately beneath the new wall, so as to push it out from the body, to which, however, it remains attached by the protoplasmic bridles. The haematochrome withdraws from the periphery, and the green colour reasserts itself, the coat thickens, and the organism conforms to the motile type. At any time a motile individual may become quiescent for a short period; this seems always to be associated with a reproductive process, which results in the appearance of the ordinary phase, sometimes known as the megazooid. Yet another form is known, the microzooid, which is small and active, and essentially like the megazooid, except as regards size. Microzooids arise by prolonged division of an ordinary body in a temporary resting phase. The body breaks up into thirty-two, or even sixty-four small pieces, each of which develops flagella, and swarms within the parent coat for a time before breaking out. The full significance of this form is not known, but it is probable that it is a conjugating individual. Two such microzooids may come together, fuse completely, and secrete a thick wall, forming what is called a 'zygote'. This is capable of withstanding cold and drought, but under favourable conditions will burst the coat and come forth in the usual form. There are, therefore, two distinct forms of

Sphaerella: large individuals, which undergo spontaneous division, and small ones, which do not live unless conjugation takes place. Such an occurrence of two different forms is known as 'dimorphism', and is frequently met with throughout the organic world. Besides the difference in size or structure, there is usually also a difference of habit, as in this instance, where the megazooids reproduce by simple division, while the microzooids conjugate first.

Like Saccharomyces, Sphaerella has an unbroken coat, and therefore must absorb its food materials by osmosis. The water in which it lives contains much nitrogenous substance in solution, resulting from the decay of various animal and vegetable matters its carbon is obtained from the carbon dioxide dissolved in the water. If water containing a sufficient quantity of green Sphaerella be exposed to sunlight, bubbles of gas will be given off and will prove to be oxygen. Further, carbon dioxide will have disappeared from the water, and the quantity of oxygen obtained will be found to bear a definite relation to this carbon dioxide. If light be excluded, all evolution of oxygen ceases at once. It is evident, therefore, that the organism has obtained carbon from carbon dioxide, and that it can do this only in the presence of light. Colourless organisms cannot get their carbon in this way yeast, for instance, must be supplied with some more complex substance such as sugar, therefore we conclude that chlorophyll must be concerned in this work. Chlorophyll is always associated with protoplasm to form chloroplasts, so a question arises as to whether the living substance plays any part in the decomposition of carbon dioxide. Chlorophyll may be dissolved out of the plastid by means of alcohol, and with the aid of the spectroscope, it may easily be seen that the solution absorbs certain rays of light, the red rays. It is known that, given energy and a supply of suitable material, protoplasm is capable of manufacturing its own or other substance. so it seems that the green colouring-matter absorbs energy direct from the sun's rays and passes it on to the protoplasm, which can then form more complicated molecules from carbon dioxide and water. Some of the oxygen is given off, and the carbon, hydrogen, and oxygen retained form carbohydrates of increasing complexity until starch is

reached. The whole process, however, is accomplished within a few minutes. The further elaboration of the carbohydrate to a protein, which may become protoplasm, is not fully understood; it seems probable, however, that the insoluble starch, formed by the chloroplast, is converted into sugar, and that from this sugar, with nitrates which have been absorbed by osmosis from the water, protein is built up. Sphaerella thus differs entirely from Amoeba in its methods of nutrition, for, instead of ingesting solid particles, it absorbs fluid substances, and, so far from requiring organic food material, it is able to build up its own protoplasm from simple inorganic matter. It is, therefore, impossible to speak of 'digestion' in this organism as we did in Amoeba, for there is no initial breaking down of complex molecules. The energy which the Amoeba obtains from the breaking down of organic food is replaced here by the energy of the sun's rays, utilized by the chloroplast. Again there is no extrusion of solid unused material; the oxygen rejected from the carbon dioxide and water has, however, never been associated with the protoplasm, and may perhaps be compared with the useless débris extruded by an Amoeba.

The nutritive processes of Sphaerella and of Saccharomyces are also unlike, for Sphaerella has the power of assimilating inorganic materials, and Saccharomyces needs already elaborated organic food. Both of these forms, however, absorb all their food through the unbroken body-wall by osmosis.

CHAPTER IV

VORTICELLA

If the stalks of water weeds, or little pieces of stick, or even the bodies of minute animals occurring in stagnant water, be examined with a lens, they will sometimes be seen to afford attachment for a minute organism, called Vorticella, larger and more complex than any that have yet been studied, but still of a very simple kind. The body is of constant form and is bell-shaped: it is fixed to the water weed, or bit of stick, by a long stalk, while the body extends freely into the water. Vorticella exhibits great irritability, and as one is watching it, will suddenly, and often from no apparent cause, shrink up with lightning speed to no more than half its former length. The body has become a roundish lump, the stalk contracted into a tight spiral. Presently and slowly the stalk straightens out, the body resumes its ordinary shape, only to fly back into the contracted state, with or without an apparent stimulus. When the animal is fully expanded, a little flicker may be noticed round the free end, which indeed seems itself to rotate, and if any small particles come within the region of the flicker, little currents and eddies are apparent in the water. The currents are caused by the constant rhythmical movement of delicate hair-like extensions of the protoplasm, called cilia, which form a fringe all round the free end. A closer examination of the body shows that it consists of the central mass of endosarc covered by a layer of ectosarc, which we noticed in Amoeba: but here the ectosarc is firm, and is further modified upon its outer surface to form a still firmer protective layer or cuticle. Immediately beneath the cuticle may be seen delicate striations, which are contractile. They converge towards the stalk, and passing into it form a central strand by the lengthening or shortening of which the stalk is extended or contracted as noticed above. The stalk contains no endosarc; it consists simply of the central cord of contractile ectosarc, with a covering layer of cuticle.

The body is turned back at the margin so as to form a sort of rolled collar, and within this is a depression into which a kind of lid, the disc or peristome, fits, leaving a furrow all round it. On one side, where the disc is slightly raised,

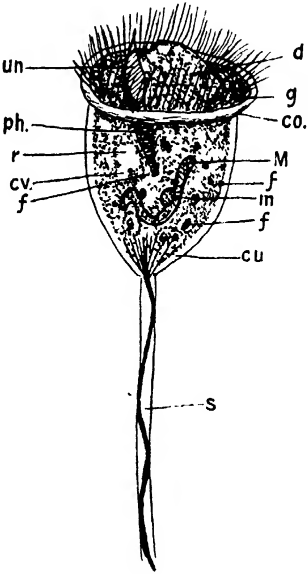


FIG 4 Vorticella.

co collar
cu cuticle
c.v contractile vacuole.
d disc
f. food vacuole.
g. furrow
M meganucleus
m. micronucleus
ph. pharynx
r reservoir
s stalk
un undulating membrane

the depression is marked by a pit, called the pharynx. Its external opening forms the mouth, the inner end leaving bare the endosarc. Such definite pores are necessitated

by the presence of the cuticle. The disc is supported by a stout peduncle formed by the inner lip of the furrow, and its appearance of being raised is really due to the greater height of this peduncle at one side. The collar is extremely contractile, and when the disc is withdrawn, gathers up over it, causing the body to assume the rounded form referred to above. The furrow is thickly beset with the cilia which have been already described, and they clothe the walls of the pharynx also. In addition to cilia, the pharynx displays an undulating membrane, a delicate structure formed apparently of fused cilia. It is attached to the pharyngeal wall by one edge, while the other projects freely into the lumen. The currents caused by the cilia waft smaller organisms or other particles to the mouth, probably with no choice on the part of the Vorticella, and they are further aided in making a way towards the patch of endosarc at the base of the pharynx by the waving motion of the undulating membrane. Particles which reach the base of the pharynx are taken in by the endosarc, 'swallowed' as it were, with a droplet of water, and at once constitute a food vacuole. The endosarc is in constant motion, as may be seen by the streaming of the granules, just as we noticed in Amoeba here the motion is rotatory, and granules and larger particles are continually carried round. The food vacuole gets caught by this stream, and as soon as it has moved away from the pharynx a new one is formed, so that in an individual that is actively feeding, a complete ring of vacuoles may be observed. As in Amoeba, digestive fluids appear to be passed into the vacuole from the surrounding protoplasm, and as they act upon the food, nutritive matters are withdrawn, and again we find that the vacuole decreases in size during its progress round the body. As it gets back towards the pharynx it disappears, and the undigested material lies in the protoplasm, near the peristome Finally it is ejected into the upper part of the pharynx, and so got rid of through another pore, the anus. A contractile vacuole is present · it communicates with a second cavity, the reservoir, rather larger than the vacuole itself, and opening into the pharynx When the vacuole contracts, its contents are forced into the reservoir, and so reach the exterior.

In Vorticella there are two nuclei one is long like a ribbon, and curved into a horseshoe, or S-shape, it is called the meganucleus. The other is small and compact, and is known as the micronucleus. The meganucleus is said to be concerned chiefly with the regulation of nutritive processes, while the micronucleus certainly takes the leading part in reproduction Reproduction takes place as in Amoeba, by the simple division of one individual into two. Meganucleus and micronucleus come to lie across the body, and then divide, while the body itself also separates into two parts, both at first attached to the stalk Soon one of the new individuals develops a ring of cilia towards the stalk end, breaks away from its attachment, and swims off by means of these cilia. Eventually it adheres to some object by its narrow end and grows a new stalk Occasionally an ordinary individual will produce the posterior circlet of cilia, break away from its old attachment, and swim off to settle down in a new place This has nothing to do with reproduction, but is probably the result of unfavourable conditions of some kind. The deserted stalks may often be found, sometimes in great numbers

As one of the products in ordinary division remains connected with the original stalk, while the other separates off, it is possible in Vorticella to distinguish between parent and offspring, the offspring being the part which breaks free Vorticella thus affords an illustration of the way in which fixed organisms avoid the overcrowding of a given spot by the development of forms which can move, or be carried away by water or wind, and so start a new settlement in another place This scattering of individuals is called dispersal.

The occurrence of the free-swimming as well as the fixed forms is another instance of dimorphism (see p 16), but Vorticella goes further than Sphaerella, and may be called trimorphic, for a third form is known in connexion with conjugation. An individual will continue to divide in the way just described for a considerable time; but at last the products of division dwindle in size, are imperfectly formed, and generally unhealthy, and they will die out altogether unless they conjugate It has been found with cultures of the organism in the laboratory that a richer

diet, such as a little Bovril added to the water, will save the stock as effectually as conjugation; but it is the latter method which doubtless obtains in natural conditions. The conjugants are an ordinary fixed individual (called a megagamete) and a small motile form (or microgamete), derived by division from a fixed one The small motile Vorticellid comes to rest upon the large one near its stalk, and at the same time the latter contracts, and its collar closes over the disc. The meganuclei in both conjugants break up and disappear, while the micronucleus of the microgamete divides into eight and that of the megagamete into four Of these only one persists in each case and at once divides again Meanwhile the cuticle and ectosarc of both conjugants have been destroyed where they came in contact, so that the two masses of endosarc are in free communication · then that of the microgamete begins to be absorbed by the large Vorticella. A further nuclear change takes place one of the two nuclei left in each body disappears, so that only one now remains in each, and these fuse to form the conjugate nucleus The protoplasm of the microgamete is entirely absorbed into the megagamete, the old cuticle shrivels up, and the zygote is complete As soon as conjugation is over the new nucleus divides three times, one of the products of division constitutes a micronucleus, the others grow larger and form meganuclei for the new Vorticellids, which are produced by rapid division, first of the micronucleus and then of the body of the zygote

Vorticella spends the greater part of its life fixed to some other body it assumes a motile form for a time only. Most of the cilia-bearing organisms are free-swimming throughout life, and they are very common in all stagnant water In hunting over slides for other specimens, a little, rather oblong body, which swims actively with a sort of corkscrewing motion, is often seen. This is Paramoecium, it swims about constantly, butting with its blunt anterior end into any foreign matter in the water, then wandering off again to butt at something else, often with an appearance of the greatest hurry. In many respects, Paramoecium bears a strong resemblance to Vorticella: the substance of the body is specialized as cuticle,

ectosarc and endosarc, cilia are present, which by their rhythmical motion cause currents towards the mouth, and the mouth opens into a pharynx which bears on its walls an undulating membrane as well as a lining of cilia. At the base of the pharynx there is an uncovered spot of endosarc where food vacuoles arise such vacuoles are carried round by the rotatory motion of the protoplasm, diminishing in size as they go, disappearing at last to leave unused matter to be extruded at the anus. In details, however, there are marked differences between the two organisms. The body of Paramoecium is covered uniformly with cilia set in longitudinal rows There is, in the substance of the ectosarc, a layer of rod-like bodies called trichocysts which, when the organism is irritated, throw out each a long thread, and serve probably as weapons both of offence and defence. Paramoecium exhibits not only an anterior and a posterior end, but also an upper or dorsal, and a lower or ventral surface. Upon the ventral surface is a groove extending from the anterior end backwards for about two-thirds of the length of the body; at the deepest part of this groove lies the mouth. The contractile vacuoles, of which there are two, one at each end of the body, are unlike that of Vorticella After a vacuole has contracted, a set of tubes, six to ten in number, and radiating from a common centre, appear and gradually increase in size. When a limit is reached they empty into

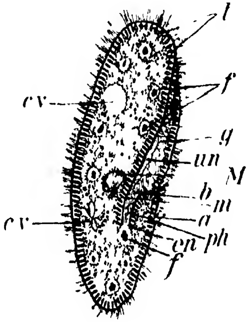


FIG 5 Paramoecium

a anus
b mouth
c v contractile vacuole
en endosarc
f food vacuole
g groove
M meganucleus
m micronucleus.
ph pharynx
t trichocysts
un undulating membrane

a central reservoir, which expands as they diminish by loss of their contents. The liquid in the reservoir is squeezed to the exterior by the shrinking together of the surrounding protoplasm.

Reproduction takes place by ordinary fission. Meganucleus and micronucleus (both of a rounded form) elongate and divide, and the body itself separates into two parts. One of them carries away the mouth and pharynx, the other has to form new ones. Conjugation, however, becomes necessary as in Vorticella, and it is in this process that Paramoecium differs markedly from the other organisms that we have studied: for instead of resulting in the complete fusion of two individuals it consists merely in an exchange of nuclear material. Two individuals seek one another out and become adherent, mouth lying upon mouth, groove on groove By the destruction of cuticle and ectosarc, the masses of endosarc come to be in contact. The meganuclei break up and are digested: the micronuclei increase in size, and each divides in a complicated way, three of each of the four parts thus formed being also digested The fourth part of each conjugant divides again to form an active portion, which passes to the other individual, and a passive portion which remains to fuse with the incoming active portion Thus each organism has a new conjugate nucleus As soon as the exchange is accomplished, the conjugants separate, and the parts which have been damaged, cuticle, ectosarc, mouth, &c., are regenerated The conjugate nucleus forms new meganuclei as well as new micronuclei, and the Paramoecia proceed to divide in the ordinary way.

A resting stage may occur in the life-history of this form; it is probably due to adverse conditions, or to a need for rest, especially after a heavy meal. The cilia are lost, and a gelatinous or even a chitinous cyst may be developed. The nuclei remain, but otherwise all the cell-organs atrophy. In this state, Paramoecium can withstand dessication even for years, and then is capable of reappearing in its usual form.

CHAPTER V

SUMMARY

WITH AN ACCOUNT OF SOME ALLIES OF THE FOREGOING FORMS

THE five organisms which have just been described show certain resemblances to, certain differences from, one another it will be well to give a little consideration to these resemblances and differences before we attempt the investigation of more complicated forms Each of these organisms consists of an individualized mass of protoplasm containing a nucleus, and to such bodies the term 'cell' has been applied. Many organisms, as we shall see later, are multicellular, or made up of great numbers of cells, but where the body consists of one cell only, as in those which we have been studying, it is said to be unicellular All our five specimens exhibit the characteristics of life, but in varying degrees With regard to irritability, for instance, yeast is the most inert, it shows little power of spontaneous movement, and little response to stimulus, Amoeba and Sphaerella are freely motile, and, with Vorticella, react readily to stimuli The metabolic processes again are essentially the same, but the food, the manner of feeding and of excretion, are different Amoeba and Vorticella require solid organic food, which they ingest with water to form food vacuoles where it is digested the nutritive parts are retained and absorbed by the protoplasm, while the valueless surplus, often quite unchanged, is extruded Saccharomyces and Sphaerella, on the other hand, absorb fluid nutriment by osmosis through any part of the body-wall, but while Saccharomyces requires organic foodstuff, Sphaerella takes in simple inorganic gases or salts. There is no real digestion or breaking down in either of these forms, though Sphaerella has to split up carbon dioxide and water as a first step in the formation of carbohydrates, and thus may perhaps be compared with

the digestion of Amoeba, just as the expulsion of the oxygen in the one case may be likened to the extrusion of unused solid matter in the other. As regards the excretory products, carbon dioxide and water are in all cases got rid of by diffusion, in Amoeba and Vorticella, however, much of the water is expelled with the nitrogenous waste by the contractile vacuoles, while in Saccharomyces and Sphaerella there is little such waste, and what there is tends to remain in the body in the form of stores, and so to be used over again for food. Reproduction may be reduced to a common type, viz. division into two, in all these forms. Variations of it are seen in Saccharomyces, where the products of division are unequal, and therefore a process of budding results or in Sphaerella, where the sequence of divisions is so rapid that even sixty-four new cells may be formed, all of apparently equal age. So far as these forms go, it would seem that long-continued fission has an exhausting effect upon the products, and hence that conjugation, the fusion of two individuals to form a zygote, is a necessary condition of continued vitality. Power and method of movement are varied · Sphaerella in the motile stage is the most active form, although it indulges in frequent periods of rest; but unless it is encysted, it swims about with great freedom, and even when it stops, may poise on its flagella, while the body vibrates rapidly to and fro In spite of its generally fixed habit of life, Vorticella shows considerable power of movement, the constant waving of the cilia and of the undulating membrane when the disc is expanded, the swift contractions or more leisured extensions of the stalk, are very noticeable; and at times it assumes an entirely locomotor form, when it swims through the water with great rapidity. The general habit of Amoeba is sluggish, yet the protrusion of pseudopodia may be vigorous, so that progression is appreciable, though never speedy. It also exhibits movements within the body, as in the case of the contractile vacuole which is even more marked in Vorticella; and the streaming movements of the protoplasm, which seem to be a universal property of living substance and thus to be looked for in all cells, are plainly visible in this form.

All these organisms exhibit great simplicity of form, seeing that each consists of but a single cell. within the

limits of the cell, however, considerable differentiation of structure may occur, and, associated with this, division of labour, or complexity of function Saccharomyces is the simplest, its general inertness calling for no specialized cell-organs. In Amoeba there is little differentiation; for its most noticeable feature, the pseudopodia, are not specialized parts of the body, but may be protruded from any part. The locomotor organs of the motile forms of Sphaerella and Vorticella, however, are well-defined cell-organs, arising in definite positions and from special parts of the cell · the same may be said of the mouth and gullet of Vorticella, and of the chloroplast of Sphaerella.

By differentiation in different ways an organism is fitted to fill some particular place upon the earth's surface, in other words, is adapted to a special environment In the examples under consideration, yeast is adapted, by its power of obtaining energy by fermentation, to survive in sugary liquids which would not be suitable for forms without this property Sphaerella is enabled to withstand the drying-up of the pools in which it lives by forming large quantities of haematochrome as it encysts it is even said that, unless such a drying up occurs to cause the change to a quiescent period, cell-division languishes and the organism dies Amoeba and Vorticella live under similar conditions, but even here adaptation is clearly seen, Amoeba 'creeps', as it were, at the bottom of pond or ditch and thus can hardly come into conflict for place with Vorticella, which is either fixed or else swims freely and rapidly by means of its numerous cilia

From this brief review of the more characteristic features of our organisms, it is evident that Amoeba and Vorticella have much in common; and that Sphaerella and Saccharomyces, while less alike, are yet closer to each other than either is to Amoeba and Vorticella To repeat Amoeba and Vorticella are identical in their mode of feeding, in the possession of excretory and digestive vacuoles, and in the absence of a specialized cell-wall It has been agreed to give the name 'Animal' to organisms exhibiting these peculiarities. Sphaerella and yeast, on the other hand, present a cellulose cell-wall and can take in only fluid nutriment, which passes into the body by osmosis Such organisms are called 'Plants'. Our two plants differ,

however, in that Sphaerella possesses a chloroplast, and can therefore make use of inorganic food, while Saccharomyces is colourless and needs already prepared organic nutriment further, in that Sphaerella is actively locomotor, while yeast is quiescent. Most plants contain chlorophyll and hence resemble Sphaerella in their manner of nutrition, the rest, which feed as does yeast, are grouped together as Fungi only a few lowly plants, however, are motile, the general idea of a plant being an organism which does not travel from place to place, here yeast is obviously plant-like.

FIG. 6 Chromulina (After Klebs)

In using the terms 'plant', 'animal', it must always be remembered that they are merely terms, and that to call anything by a particular name does not give to that thing any special properties. it is rather from the properties of an individual, or group of individuals, that a name is invented to indicate separation by these characters from other individuals or groups The fact is that the organism is the reality and that the names which are applied to it, as an individual, or as one of a group, are merely matters of convenience The division of organisms into plants and animals is the first stage in their classification or sorting out It is a very old division, the earliest of all indeed, and dates back to a time when none of the lowlier forms could be known since there were no microscopes nor even lenses. If only the higher types are considered, it is easy to make this division, but when we come to unicellular organisms, a sharp line of separation cannot be drawn for although it is agreed to regard generally as animals those individuals which are motile, are destitute of chlorophyll, have not the power of secreting cellulose, possess contractile vacuoles, and feed upon solid organic material and as plants those which are quiescent, possess chlorophyll, secrete cellulose, and feed entirely by osmosis yet we have seen that Sphaerella, which feeds like a plant,

is also motile, a condition occurring in many like forms. One of these, Chromulina (Fig. 6), may be mentioned because it has, on the one hand, a mouth and a contractile vacuole, and on the other, a chloroplast and, in the encysted state, a cellulose coat Again, the method of nutrition which we have noticed as characteristic of Fungi, is by no means unknown among forms which can only be called animals. It occurs almost universally

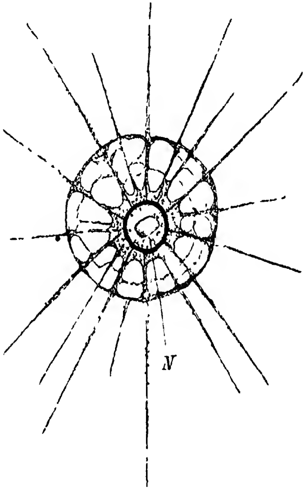


FIG 7 Young Actinosphaerium (From Sedgwick) N nucleus

among parasites, as, for example, in the unicellular Opalina, which lives in the intestine of the frog.

In this book no attempt is made to give any kind of detailed classification, such must be sought in textbooks of zoology and botany. We shall notice, however, in dealing with any set of organisms, some of the other forms which resemble them, and try to indicate in what directions the lines of development lie. Of unicellular organisms,

great numbers are known, and they exhibit an almost endless diversity of form. There are those which, like Amoeba, are entirely destitute of any sort of external membrane or cuticle, and can therefore protrude pseudopodia. They can always be recognized as near relatives of Amoeba from this peculiarity. Sometimes the pseudopodia have a definite position; when retracted they can

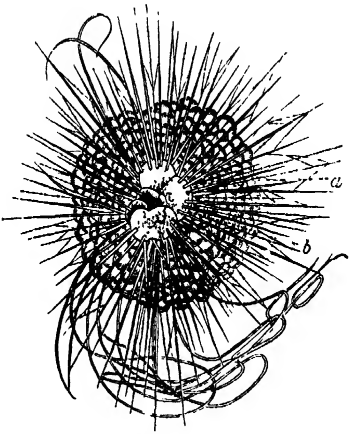


Fig. 8. Globigerina (From Sedgwick.)
a. protoplasm outside *b*. shell.

be extended again, but always from the same spot (Actinosphaerium, Fig. 7) What leads, however, to the greatest variety of form is the power which some Amoeba-like cells have of secreting a shell of lime, silica, or chitin (Globigerina, Raphidococcus, Arcella, Figs. 8, 9, 10). The material for the shell is obtained from the water in which the organism lives it is secreted by the activity of the protoplasm and deposited in very different ways, so that a large variety of most beautiful designs results. The individual shells are very tiny, and yet in the case of those composed of lime salts, they constitute great masses

of the earth's crust. The chalk beds which are so frequent in England, and break out as cliffs on many parts of the coast, are almost entirely formed of the shells of millions of these microscopic animals which lived in much earlier geological times

Among free-living cells possessed of a cuticle perhaps a greater diversity of form is known. They do not secrete shells, but the body-substance itself tends to show great modification. The firm outside layer necessitates greater elaboration of cell-organs; and so, as in Vorticella, mouth and anus in connexion with nutrition, cilia for the production of currents (originally in the service of locomotion) arise A great many exhibit flagella (e.g Sphaerella), by the lashing of which they move through the water with great rapidity, and then the body may be very pliant and may bend and twist to a considerable extent (Euglena, Fig. 11). Organisms possessing flagella are often brightly coloured, green (chlorophyll), red or brown. The water off North-West America may be so populated with one form (Noctiluca, Fig. 12) as to acquire a bright orange tint, and be compared by Professor Haeckel to 'tomato-soup'. Flagellates also often impart to water distinct odours, which may be pleasant or otherwise. A Euglena is said to cause a perfume like violets, while a most unpleasant smell is given to drinking-water by Uroglena.

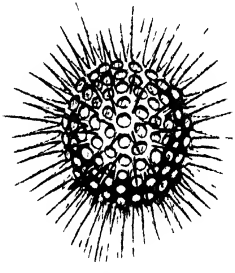


FIG 9 Raphidococcus (From Butschli)

Most of the forms exhibiting cilia are free-swimming, then the cilia may be arranged uniformly over the body (Paramoecium), or they may be restricted to one part, whilst scattered about are larger projections, bristle-like outgrowths, &c., though these are probably modified cilia (Stylonychia, Fig 13). The cilia also often show a tendency to adhere to one another and thus form undulating membranes. Vorticella is a good example of

a fixed ciliate, with the cilia at the free end only; and sometimes, in forms allied to Vorticella, the products of division do not break away from the stalk, so that many

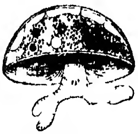


FIG 10 Arcella (From Lang)

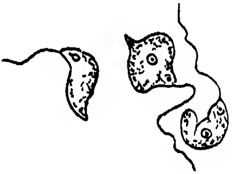


FIG 11 Euglena (After Saville Kent)

individuals are attached to a common stalk and a colony results (Epistylus). As a very peculiar modification the cilia may be lost in early life, their place being taken by longer, firmer processes with either a terminal sucker

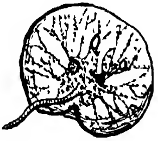


FIG 12 Noctiluca (After Saville Kent)

FIG 13 Stylonychia (After Saville Kent)

or a sharp thorn at the free extremity (Acineta, Fig. 14): such organisms are fixed, and the tentacles, which are set at the free end, serve to catch the food

A great many unicellular forms are parasitic: cells

essentially like Amoeba are found in the digestive tracts of many higher animals. Flagellates cause some of the worst diseases to which man and the higher animals are subject (sleeping-sickness, &c). The Sporozoa, all of which are parasites, are destitute of most of the usual cell-organs—mouth, contractile vacuole, food vacuoles—and are very frequent in the tissues of other animals where they may provoke great disturbance. With this great simplification of structure is found a very elaborate life-history, the organism passing through many peculiar stages, probably to ensure its finding its way into the body of the particular animal which affords it protection. It will be well to see

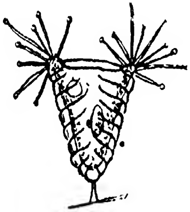


FIG 14 Acineta (After Saville Kent)

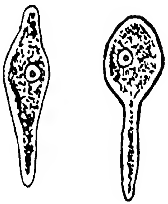


FIG 15 Monocystis (After Butschli)

how complicated the life-history, even in such simple animals, may be, and so we will consider briefly two that of Monocystis (Fig. 15) which lives in the pouches containing the motile reproductive cells of the earthworm, and Haemamoeba (Fig 16) which gets into the blood of Vertebrates and causes diseases such as malaria

Monocystis has a rather elongate body of which the outer layer is somewhat contractile A nucleus is present, but otherwise we look in vain for cell-organs such as are to be found in the other organisms which we have studied When mature, two individuals come together and surround themselves with a protective case and so form a cyst Each then divides into a number of gametes, which proceed to conjugate, the gametes from one parent cell always uniting with those from the other, so that a number of

zygotes are formed, and each of them becomes invested with a thick coat. The nucleus of the zygote divides, and the protoplasm with it, to form eight long narrow cells so that within the original cyst there are numbers of zygotes, and within these again small new cells. The

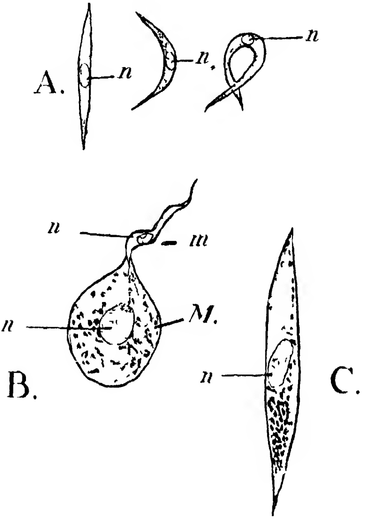


FIG 16 Haemamoeba (After Schaudinn)

A Spindle-shaped bodies in various positions
B Union of microgamete, *m*, with macrogamete, *M*
C Zygote
n nucleus

cysts are freed from their host, and by the bursting of their walls the zygotes are liberated These find their way into a fresh earthworm, and, once inside the wall, rupture and the new little parasites burrow afresh into the reproductive cells

The life-history of Haemamoeba is far more complicated. This form attacks red-blood corpuscles, entering as

a small spindle-shaped body, but rapidly growing at the expense of the corpuscle into an amoeba-like form. When fully grown it breaks up into spores in the usual way, and the spores turn into the little spindle-shaped bodies and attack new corpuscles This may go on for an indefinite length of time, the tiny invaders multiplying with great rapidity; usually, however, some of them are removed by the agency of a special kind of gnat, which, in drawing blood from its victim, draws Haemamoebae too Within the gnat, gametes are formed. As in Vorticella, there are megagametes and microgametes the former are rounded, the latter much like long flagella. The zygote is at first rounded, but soon elongates, and bores its way out of the digestive tract of the gnat It then forms a cyst, and, like the zygote of Monocystis, breaks up into new spindle-shaped cells These are set free and find their way to the glands near the mouth of the gnat, and so are introduced into the blood of its next victim. The occurrence of the second host, the gnat, in this life-history, is undoubtedly an adaptation of the organism to ensure its reaching a new specimen of the first host

The simplification of structure which such forms exhibit is very interesting, as being due, probably, to the parasitic habit. Parasites live in the midst of plenty, obtaining all their food from the tissues of the host therefore organs for seeking or ingesting food are superfluous, and since the food is already prepared, elaborate arrangements for its digestion are unnecessary Where the animal lives on the blood of its host the intervention of a second host which itself feeds upon blood is clearly necessary to ensure dispersal

All the foregoing organisms and their immediate allies may fairly be classified as animals the Flagellates present the most doubtful cases, and may, perhaps, be the group in which differentiation gave rise to the earliest plant development Sphaerella, with its definite outline and waving flagella, recalls this group, but it is more specialized in having a cellulose cell-wall Its allies are very numerous, sometimes bearing flagella, but often with less noticeable means of locomotion. Of these, the Desmids (Fig. 17) may be mentioned, bright green in colour, and exhibiting many and beautiful outlines. They are found in great

numbers in ponds and fresh-water lakes, and are generally quiescent, just floating in the water, though they are capable of executing vigorous movements, especially under the influence of light. Much like these, but differing from them in their brown coloration, are the Diatoms (Fig 18), which are both fresh-water and marine, occurring in large numbers in surface-waters. they also are usually passive,

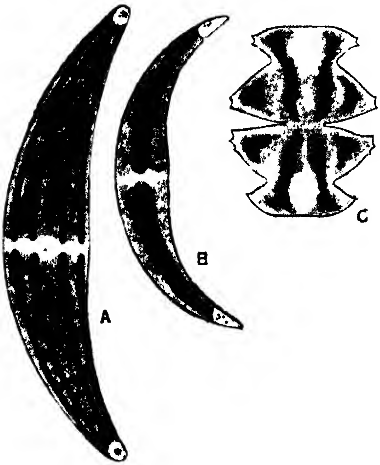


FIG 17 Desmids (From West)

but are capable of spontaneous movements. They are of some importance geologically, for the cellulose cell-walls become so impregnated with silica as to form well-defined shells, and these, like the shells of the unicellular animals referred to on p. 30, constitute considerable deposits Tripoli (Kieselguhr), for instance, so largely used in the manufacture of dynamite, is composed of masses of Diatoms. Both Desmids and Diatoms are frequently to be seen on the slide when one is hunting for other minute organisms, and in forms such as Amoeba they may occa-

sionally be seen within the body of the animal, having been ingested as food.

Finally may be mentioned the Bacteria, which are more nearly related to Saccharomyces. They are motile and of a very minute size. There is a definite cell-wall, which is not, however, formed of cellulose, and the nuclear material, instead of being always aggregated in one mass, seems usually to be scattered in a finely divided condition throughout the body. These organisms are the cause of much of the discomfort in the world, for to their living activity is due the putrefaction of meat, the souring of milk, the turning of butter, and other like troubles; also the occurrence of such diseases as measles, fevers, influenza. Many Bacteria are quite harmless, but, innocent or malignant, their spores occur in great numbers in all kinds of dust and tend to be blown about in all directions. If 'tea' be made by pouring boiling water upon hay, and it is left to stand, the liquid becomes turbid, and if then a drop be examined with the microscope, swarms of the hay bacterium, *Bacillus subtilis* (Fig. 19), will be visible. The cells are very tiny, much smaller than any we have yet seen. They are rod-shaped and uniformly covered with cilia. At first they are exceedingly active and reproduce with great rapidity. After a time they rise to the surface of the liquid and lose their cilia. The cell-wall becomes gelatinous, and the cells arrange themselves end to end to form long chains, and these are massed together so as to form a film over the liquid. This quiescent phase gives place, when the food in the hay-infusion begins to be used up, to active spore formation. The protoplasm in a cell rounds together and secretes a new coat within the old one, which it nearly fills. The spores are exceedingly difficult to kill; they will withstand complete drying up, and extremes of temperature; spores of the hay bacterium, for instance, are not affected by boiling water. It is for this reason very important to exercise great care in 'disinfecting', when harmful bacteria are known to be present.

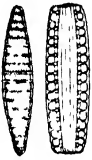


Fig. 18. Diatoms. (From West.)

The spores, after undergoing what are apparently the most adverse circumstances, will germinate freely as soon as they reach suitable conditions

We see now that the lines of development among those unicellular forms which are regarded as animals are four in number, and among those which are usually ranked as plants, two. We may take as the least specialized, Amoeba

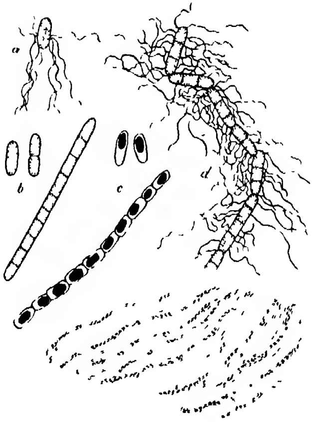


FIG. 19 *Bacillus subtilis* (From Fischer)
a motile short form *b*. non-motile rods and chains. *c*. spores in chains which unite to form the surface scum *e* *d* motile chains

and its allies, with their naked protoplasm and their power of protruding pseudopodia Modified for a different kind of movement are the flagella-bearing forms, with a small and definite number of flagella, and with, generally, a definite outline owing to the formation of an external cuticle It is here that it is most difficult to discriminate between 'plant' and 'animal', and by most Botanists those Flagellates which possess chlorophyll are claimed as plants. From them. it is, indeed, no very long step to

Sphaerella and to the green plants generally; but a connexion with Saccharomyces and the other Fungi is not so easy to see. The third of the lines of animal development gives us Vorticella and its relatives in which the cuticle is better defined, and the protoplasmic extensions for locomotor purposes are smaller, but far more numerous than in other groups. The ciliate forms are among the most highly specialized of all these lowly organisms. The fourth line again is much modified but in a backward direction, for if we suppose all these lines to be connected with one another, we can only think that the Sporozoa which show so few cell-organs, must have been differentiated from organisms possessing them and because of their parasitic habit. The connexions to be traced in this way between organisms differing, often to a great degree, in form and structure, have led to the formulation of the law of evolution. We find throughout the organic world that the more complex may be traced back to the less complex; and all the evidence at our disposal goes to show that the more elaborate have been evolved by modification of simpler organisms. As more complicated organisms are studied, differentiation of structure, division of labour, adaptation to surroundings, will all be seen in higher specialization; but we shall at the same time find it interesting to note how all the essentials of structure and function are foreshadowed in these simple forms.

PART II.

SIMPLE MULTICELLULAR ORGANISMS

In Part I it has been shown how great a variety of form, structure, and mode of life occurs even among unicellular organisms, and it has been pointed out at the same time how, underlying the diversity, a certain similarity of structure can be traced, in that each organism consists of a tiny mass of living substance, which has been differentiated into two unlike parts, one forming the general body-substance, the other the nucleus. In all cases, moreover, the latter seems to have some special power of controlling the former, as seen, for instance, in the process of reproduction, where the cell-substance simply follows, as it were, the lead of the nucleus, gathering itself together around the different nuclear centres and giving rise to two individuals in the place of one In the higher organisms a similar differentiation between the nucleus and the general protoplasm of the body is found, but when nuclear division takes place it is followed by only a partial rounding off of the protoplasm, and adjacent masses remain to some degree in continuity, though apparently each nucleus still controls its own special portion of the general body-substance. Repeated division of this sort gives rise, of course, not to separate individuals as in the case of Amoeba, but to a complex body which attains an individuality of its own, wherein that of each separate nucleated mass is merged with more or less completeness. If the nuclei lie imbedded in one apparently continuous tract of protoplasm, the body is said to be multinucleate If, on the other hand, the boundaries which limit the mass under the control of each nucleus are visible and distinguish it clearly from its neighbours, each mass with its controlling nucleus is called a cell, and the body is said to be multicellular. The completeness of division of the protoplasm is merely

a question of degree, and the terms 'multinucleate' and 'multicellular' correspond to no very important distinction in structure.

The term cell is a peculiarly inapplicable one, for, strictly speaking, the word implies merely a space enclosed by walls, as in the cell of a prison, and its employment in the present sense can only be appreciated by a knowledge of the way in which it came into use as a biological term. If the stem of a herbaceous plant be cut across, a careful examination, even with the naked eye, will often reveal a kind of chambered structure. As long ago as 1665 a celebrated Botanist named Hooke pointed out that this characteristic is widely distributed among plants, and gave the name of 'cells' to the little box-like cavities which he described. Later, the cells were observed often to possess colourless semi-fluid contents, but it was not till the nineteenth century that careful examination of the minute structure of plants resulted in the discovery by Robert Brown of a denser body, the nucleus, lying in the 'cell-contents' or 'plant-slime.' Gradually as more and more organisms were observed and described, the underlying unity of structure of all living things forced itself into notice. 'There is one universal principle of development for elementary parts of organisms, however different,' said the great German investigator Schwann, in 1839, 'and this principle is the formation of cells.' The discovery of 'cell-contents' and nucleus was destined to exert a wider influence than the early observers themselves were able to foresee, for, though they regarded the nucleus as of great importance in the origination of new cells, there was still an erroneous tendency to look upon the wall or 'membrane' as the seat of real activity when the cell was fully formed.

By degrees attention became concentrated on the plant-slime or protoplasm, owing partly to the more thorough study of cell-division, and partly to the discovery that, while something resembling a cell-structure could certainly be found in the bodies of animals, the small nucleated masses of protoplasm were not surrounded by a differentiated cell-wall. Thus gradually it came to be recognized that it is the semi-fluid protoplasm, not the wall, which is the seat of vital activity. The changed point of view

which this implies altered, but did not lessen, the importance of Schwann's great generalization; and, with the progress of research, the fundamental likeness in structure of all living things has been shown more and more clearly. Not only are such diverse organisms as trees and quadrupeds formed of the same kind of substance (protoplasm, p. 3), but this substance is found to be arranged in similar tiny masses more or less continuous with each other, each under the control of its own specialized nucleus. While knowledge of the structure of living things has thus steadily progressed, until to-day we have a conception of cell-wall, protoplasm, and nucleus absolutely different from that of the early observers, the old term 'cell' has been retained, the meaning attached to it undergoing a gradual evolution through successive generations of Biologists; so that at the present time the original meaning has been completely lost, and the word is used to denote a tiny mass of protoplasm containing a nucleus. In this sense, the old generalization, that all bodies are composed of cells, is still true, but it must be borne in mind that the cells which compose the living body may be very varied in form, and that they hardly ever occur as clear and independent units. Usually when division takes place, the separation of the two masses is incomplete, and thus there is maintained a continuity of living substance throughout the organism.

CHAPTER VI

SPIROGYRA

AMONG the simplest of multicellular organisms is the fresh-water weed known as Spirogyra, the long, vivid green, hair-like threads of which may often be found floating together in dense masses in stagnant or slowly flowing water If a few threads be gently separated in the water, it will be found that they are long, very thin, and quite unbranched All parts of the filament appear alike, and, if cut into any number of portions, each will continue its life undisturbed, thus showing its practical independence of the rest

Under a low power of the microscope, one of the first things to be observed is that the green colouring matter (the same as that found in Sphaerella) is not evenly distributed throughout the body At first sight there appear to be two sets of green bands running in a somewhat oblique fashion across the thread in two directions, nearly at right angles to each other Careful focussing reveals, however, that the two sets of bands really form one continuous, ribbon-like chloroplast, which winds in a spiral manner around the thread, broken only at certain regular intervals Surrounding the whole thread, and also passing across it at places where the chloroplast is broken, is a colourless cell-wall against which the finely granular, colourless protoplasm is so closely applied that its distribution can only be clearly seen when it is caused to contract away from the outer cell-wall, as it can be made to do by running methylated spirit or salt solution under the coverslip. It remains, however, spread out against the transverse septa, through tiny holes in which it maintains continuity with the protoplasm on the opposite side. Only the specialized portion of this thin layer of protoplasm which forms the chloroplast is readily visible under normal conditions, and in this can be seen large whitish

pyrenoids like those described for Sphaerella (p. 14). The remainder of the protoplasm is, as in Saccharomyces (p. 9), highly vacuolated, only thin strands of living substance remaining to connect the outer layer or primordial

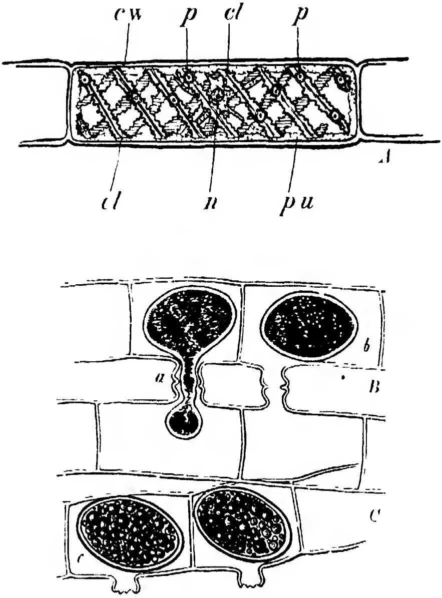


FIG 20 Spirogyra

A Part of thread, showing
cl chloroplast.
c w cell-wall
n nucleus
p u primordial utricle
p. pyrenoids
B Cells of two threads preparing for conjugation
a, b formation of bridges

C Formation of zygotes
a protoplasm of one cell passing by bridge to opposing cell of another thread
b conjugate body
c zygote, surrounded by a cell-wall
(B and C from Goebel)

utricle, as it is called, with a central mass which surrounds the nucleus

The whole thread is, then, a chain of somewhat brick-shaped cells set end to end, all similar, all capable apparently of independent life, almost completely separated by dividing cell-walls, yet still maintaining continuity with each other, and merging their individuality in some slight degree in that of the thread In all probability they derive some benefit from this association

The nutrition of Spirogyra is in all essentials like that of Sphaerella As in the latter the complete enclosure of the living substance of the body in a cell-wall necessitates that food shall be absorbed in solution, while the presence of chlorophyll gives the power of obtaining nourishment from the carbon dioxide dissolved in the water in which the plant lives. Each cell, it should be noticed, exposes the greater part of its surface to the water, and thus each is able to obtain for itself the necessary supplies of nourishment.

Growth in the individual cells leads to cell-division, new transverse septa being formed as the two masses of protoplasm gather themselves round the daughter-nuclei This reproduction of cells, however, results no longer in new individual organisms, but only in increase of the length of the thread Reproduction of the thread may take place by the simple process of its severance into two parts, each of which grows independently after separation, or as the result of the conjugation of two cells belonging to different threads Two threads come to lie side by side and the chloroplasts break up, while the protoplasm of each cell shrinks from the cell-wall and forms a central mass, which is a gamete Hollow protuberances appear on the adjacent walls of cells lying opposite to each other, grow out, and meet, and by the breaking down of the dividing partition an open channel is formed. Though no distinction can be observed between the gametes of the two threads, a difference of behaviour is soon noticeable; all the gametes in one thread remain motionless, while those in the other pass through the communicating channels and fuse with the neighbouring gametes of the other thread. The old cell-walls of one thread are thus left behind as an empty, useless case, and gradually decay,

while the protoplasm enters on a new phase of activity. Complete fusion of the two cells takes place, nucleus uniting with nucleus and protoplasm mingling with protoplasm to form a zygote, which immediately proceeds to protect itself from adverse conditions by secreting a thick envelope In this state it can lie dormant through the winter, or through a season of drought; but with returning healthy conditions the zygote will rapidly swell up, burst its coat, and grow and divide, giving rise to a fresh Spirogyra filament.

CHAPTER VII

MUCOR

If almost any organic material, bread, leather, jam, &c., be left exposed to the air in a damp place there may appear on its surface spots of different colours, which develop into little furry-looking masses of mould If the conditions remain unchanged probably the mould will spread over the whole surface of the material, but if these conditions be altered in any way, so as to render them unfit to support life, as by complete drying of the substance, or by subjection to a very high temperature, growth will be arrested Mould is, in fact, a living organism which maintains its life and grows at the expense of the substance on which it is found. This substance may be itself a living animal or plant, and the mould may prey upon it as a parasite, or it may be dead, and the very processes of decomposition may furnish the necessary conditions for the appearance and healthy growth of the new form of life In the latter case a casual observer may be at first tempted to believe that the living mould arises as a kind of product of decay from the bread or other material. Such an explanation would indeed have been accepted by the older Biologists, who firmly believed in the spontaneous generation of living forms from non-living material At one time it was even seriously maintained that the mud of the Nile bred mice, while flies were supposed to arise from the processes of putrefaction in meat It was not till the researches of Redi, in the seventeenth century, definitely proved that no flies arose from meat which had been protected from visits of other flies, that the belief in the spontaneous generation of even highly organized creatures was discredited. Much more careful work was needed to prove that the lower forms of life also only arise by generation from other living organisms, but in the middle of the last century it was shown by Pasteur and others that if a sub-

stance be so heated that no living germs can keep their vitality within it, and if it be then kept from the air or only exposed to air filtered through cotton-wool, no signs of life appear. It has come, therefore, to be generally believed that life does not begin afresh, at least under

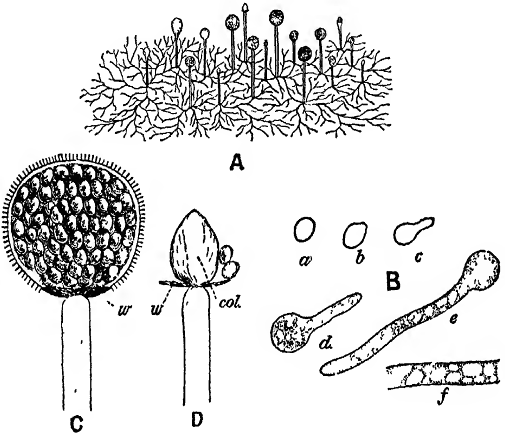


FIG 21. Mucor (From Darwin.)

A Diagrammatic sketch showing the mycelium and the sporangia borne on vertical hyphae

B *a*-*e* Various stages in the germination of a spore
f mycelium with vacuoles

C Ripe sporangium containing spores and covered with a coating of calcium oxalate crystals
w the collar.

D A burst sporangium
col columella to which two spores adhere
w collar

the present conditions of the earth's surface, but arises only by generation from already existing organisms. That the complete exclusion, or at least the filtering, of the air is necessary for the success of the experiments points to the fact, now fully recognized, that the ordinary atmosphere is stocked with myriad living germs, reproductive bodies derived from many different organisms.

They settle in the dust which gradually accumulates on undisturbed objects, and only await suitable conditions to awake to a more energetic vitality, and thus manifest their presence. It is to some of the many different kinds of germs carried everywhere by the currents in the atmosphere that we must look for the origin of the furry patches

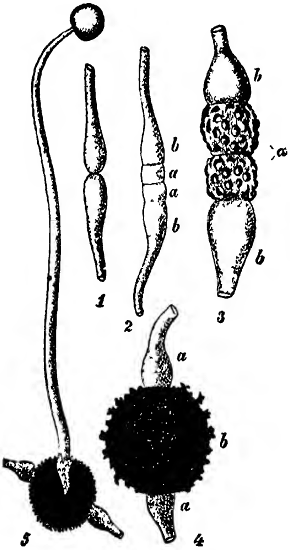


FIG 22 Stages in the formation and germination of the zygospore of *Mucor mucedo* (From Goebel)

of mould appearing on decaying substance. If the suitable conditions be given the growth is sure to arise. Mucor, the mould which will be described here, may readily be obtained by soaking a piece of bread in water and putting it under an inverted tumbler to prevent too great evaporation. When fully developed it appears as a close growth

of fine white upright threads or hyphae, each surmounted by a little swollen, opaque, dark-coloured head. Microscopic examination shows that threads similar to these, except that they have no swollen ends, lie closely over the whole surface of the bread, and even penetrate into its substance, forming a tangled mass which is known as the mycelium.

The structure of a single hypha of Mucor is very simple. Outside is a firm resistant cell-wall, inside is a more or less continuous mass of finely granular colourless protoplasm, in which staining reveals a number of irregularly arranged nuclei. There is no clear separation of the masses of protoplasm under the control of different nuclei, and transverse septa only very rarely occur. Growth in length takes place not all along the threads, as in Spirogyra, but entirely at the ends, where the protoplasm is especially active.

The development of the heads at the top of the upright hyphae can be fairly easily made out if a number of threads at different stages of growth are examined under the microscope The first sign of specialization of structure is seen in a slight swelling at the top of the upright hypha. As the swelling increases, the protoplasm which it contains becomes cut off from that in the stalk by a transverse septum, and the greater part gathers itself together into definite little masses around the several nuclei. Each mass surrounds itself with a cell-wall, and is a spore. Meanwhile, the remainder of the protoplasm degenerates into a kind of gelatinous material in which the spores lie embedded. The septum dividing the head from the stalk has also been undergoing changes, rapid growth causing it to bulge far into the cavity of the head where it forms a structure known as the columella. The outer wall of the hypha now becomes dark-coloured and chemically altered The touch of a drop of water causes a swelling of the mucilaginous material, the increased pressure within bursts the wall, and the spores are set free. The columella is then left as a small oval knob at the apex of the hypha, the wall of the sporangium being represented merely by a little ragged frill or collar at the base of the columella.

When the number of spores issuing through the broken

wall of the sporangium are watched under the microscope, and their size is compared with that of the whole head, and when an effort is made to imagine the same number of bodies packed within the tiny knob seen by the naked eye, it becomes possible to realize how these minute reproductive bodies exist in numbers in the atmosphere without our being able to detect their presence, each one waiting only for suitable conditions to pursue its own particular path of development

Occasionally a different method of reproduction may be observed in Mucor Two hyphae lying side by side on the surface of the bread may send out each a tiny projection towards the other These projections meet and the dividing wall becomes absorbed Meanwhile a mass of protoplasm at the end of each, containing a single nucleus, has become cut off from the basal portion of the projection by the growth of a transverse septum The two protoplasmic masses, now known as gametes move towards each other and fuse completely, forming a zygote which immediately secretes round itself a very thick, firm wall It is isolated by the rotting away of the basal portions of the projections, and, protected by its hard covering, can lie dormant for a long time, unaffected by unfavourable conditions When these are changed, the dormant life becomes active, and by rapid growth a new mycelium develops The formation of the zygote, of course, is the result of conjugation

The absence of chlorophyll necessitates a mode of existence completely different from that of Spirogyra Like yeast, Mucor is unable to make use of carbon dioxide as food, and needs both carbonaceous and nitrogenous compounds of a more or less complex nature These it finds in a suitable form where animal or vegetable substances are passing into a state of decay Probably it assists the process of dissolution, and at the same time renders its own food material soluble by the secretion of ferments. The broken down protein material is then absorbed by the hyphae and built up once again into the substance of a living body

Respiration takes place over all parts of the body which are exposed to the air, and in this manner most if not all of the carbonaceous waste is excreted. Many of the waste

products in plants, however, do not immediately leave the body (p. 26); they often pass into a crystalline form and are stored in the cell-walls, or even in the cell-substance, frequently in parts of the plant which are shortly to be thrown off. In Mucor, just before the ripening of the sporangium, crystals of oxalate of lime, which may probably be regarded as a waste product, are laid down in its wall, and are, of course, got rid of when the wall itself shrivels up and drops away.

In comparing Spirogyra and Mucor it is at once observable that there is a division of labour and an unlikeness of parts in the latter which is completely absent from the former. It is tempting and perhaps justifiable to connect the greater differentiation of parts in Mucor with its adaptation to the conditions of life on dry land, for whereas in Spirogyra every cell is equally bathed by the water from which it obtains its food, and into which the reproductive cells are shed, in Mucor, part must be closely in contact with the substance on which it grows, and so be in a position to absorb nourishment, while part must lift the reproductive cells above the surface of the food substance, in order that they may be carried away from the parent plant and find fresh material on which to grow.

CHAPTER VIII

SOME FORMS ALLIED TO SPIROGYRA AND MUCOR

THE presence of chlorophyll may be regarded as linking Spirogyra to Sphaerella, and, in the same way, its absence, as connecting Mucor and yeast Mucor is in fact, just as is yeast, one of the Fungi (p 28) while Spirogyra and Sphaerella are grouped with a large and somewhat miscellaneous collection of aquatic plants, all of which contain chlorophyll, as Algae Unicellular plants are not classed together as are unicellular animals for they do not show in any way the same relationships or progressive complexity so in this big group Algae (which is now broken up by many Botanists) are included forms as simple as Sphaerella and the Diatoms and Desmids, many as complex as Spirogyra, and some of still greater specialization. In the same way, plants grouped as Fungi are as simple as yeast or as complicated as the mushroom

For our present purpose, we will retain the term Algae Algae are distinguished at once by their brilliant colouring, all, of course, possess chlorophyll, but in many forms the green is masked by other pigments, chiefly brown and red Spirogyra is green, and is of a very simple structure, consisting of a number of similar cells placed end to end to build up a long thread This thread-like body is very common among Algae another green form, Vaucheria, also frequently met with, sometimes in water, sometimes on damp earth, resembles Mucor in that its growth is apical, and its threads are unseptate, the protoplasm being continuous except at those points where reproductive cells are being formed, and containing many scattered nuclei. Vaucheria shows a differentiation of gametes not found in Spirogyra these are large quiescent cells or ova, and tiny motile cells, the spermatozoids, which travel to the ova and conjugate with them. The zygotes

thus formed develop just as do those of Spirogyra; but there is another kind of reproductive cell which does not need fertilization, and may therefore be compared with the spores of Mucor. Both kinds of cells, however, zygotes and spores alike, give rise to identical Vaucheria plants, long, green, unseptate threads, each attached to

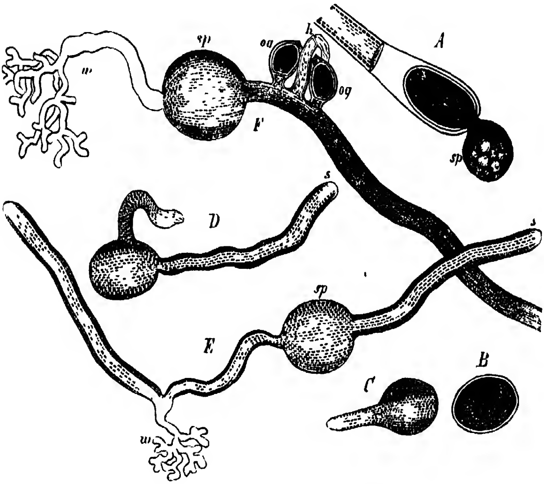


FIG 23 Vaucheria (From Goebel)

A. Formation of a spore, *sp*
B, C, D Stages in the germination of the spore
In E the rhizoids, *w*, and the growing point, *s*, are marked
In F reproductive organs may be seen, *og*, *h*.

the earth by its tuft of colourless root-like filaments or rhizoids

Another common green water-weed is Chara (Fig. 24), which shows quite a considerable complexity of organization This plant is very common in ponds and streams, where it is fixed to the bottom by white rhizoids. It often attains a length of a metre or upwards, and the green 'stem' branches, so that its appearance is much like that

of the higher plants. In spite of this appearance, the entire plant, including the rhizoids, is composed essentially of elongate cells placed end to end The branches are given off from thickenings formed by clusters of cells called 'nodes' the 'internodes' or spaces between the nodes may attain a length of three or four centimetres, and consist each of a simple central cell which, however, may become surrounded by a covering of smaller cells derived from the nodal cluster The gametes are found in special organs situated upon the nodes The spermatozoids are motile, and are shed into the water, while the ovum is quiescent. A spermatozoid reaches an ovum and conjugates with it, and from the zygote thus formed a new plant is developed Reproduction by spores does not occur in Chara

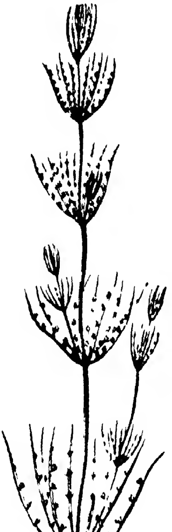


FIG 24 Chara Portion of shoot The whorled 'leaves' which bear the reproductive organs are short shoots (From Goebel)

Of sea-weeds a very great variety is found, green, red, and brown It will be sufficient here just to mention one of the best known, Fucus, the 'bladder' sea-weed, with its brown body beset with air-vesicles. This plant is far more complicated than any we have yet noticed. It is attached to the sea-bottom by rhizoids, and the upgrowing part is differentiated into a tough axis and leaf-like lateral expansions. The cells of the expansions serve to elaborate food, while those of the axis carry the nutriment thus prepared Growth is not limited to the tips of the branches, but occurs also in the lateral cells As in Chara, the gametes arise in special organs The tips of the branches become much swollen, and look gritty.

The 'grits' are really little crater-like protuberances, in the cavities of which the reproductive organs are lodged. Ova and spermatozoids may occur on the same branch and even in the same depression, or may be confined to distinct plants. The air-vesicles to which the popularity of this sea-weed is due are simply much swollen spaces left between the cells of the lateral expansions, and serve to keep the plant upright in the water.

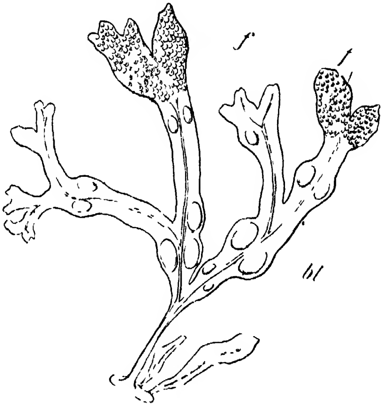


FIG 25 Fucus
f reproductive branches bl. air-vesicle.

Turning to the Fungi we find that under suitable conditions most organic substances will in time become mouldy, and very little observation is needed to show that the nature of the mould varies widely with different materials. Diverse, however, as moulds may be in their colour and form, they are for the most part essentially similar in their structure and manner of life, all possessing a mycelium with absorbing hyphae, and an aerial spore-bearing apparatus. This latter organ presents two well-marked types which can easily be distinguished by an examination under the low power of the microscope. One type has

already been described in Mucor, the other is found in Eurotium, a mould which frequently occurs on jam or dried plants, and some other vegetable substances, in furry whitish patches Here the spores do not arise in the interior of a sporangium, but on the outside of the swollen head of the upright hypha. A number of little projec-

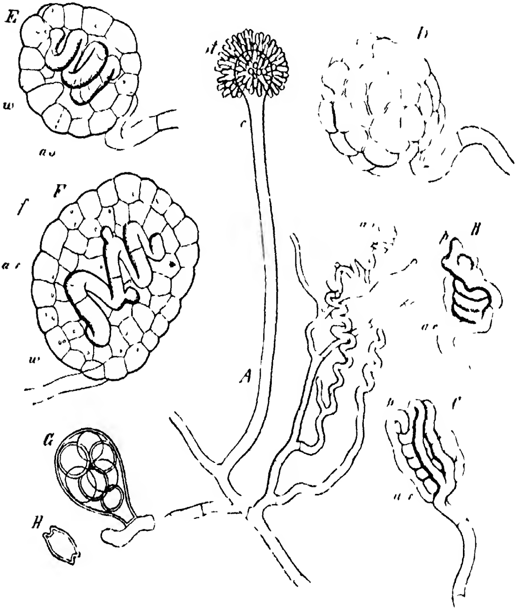


FIG 26 Eurotium (After de Bary)

A A small part of a mycelium with club-shaped aerial hypha (c) bearing sterigmata (st)
as coiled reproductive hypha
B Conjugating hyphae (*as*, *p*)
C Sterile hyphae growing over conjugating mass

D Cleistothecium
E and F sections of developing cleistothecia
w external wall
f packing cells
G An ascus
H A ripe ascospore

tions, the sterigmata, at first appear all over the surface of the head, and as these increase in length the ends become constricted off to form the spores. Sometimes a whole chain of spores may be formed by successive constrictions. Eurotium has also another and much more complicated method of reproduction, resulting from a kind of conjugation. One of the hyphae becomes tightly coiled at the top From the base of the coil spring certain branches which grow up to the apex, and at the same time increase in girth, becoming meantime divided by longitudinal walls till at last they form a complete single-layered coat to the inner coil It is not quite certain at what stage conjugation takes place, but it is thought that the tip of the coil fuses at some time with the tip of one of the upright hyphae, or that something passes from the latter into the former. However this may be, rapid growth proceeds, the cells of the outer coat send prolongations inwards among the coils of the spiral, and these inner portions are separated off by cell-walls, so that a complete solid multicellular body, known as a cleistothecium, is formed. Meanwhile, on the outer side of the spiral, small oval swellings appear, each of which develops into a little box, known as an ascus, containing eight ascospores. As the cleistothecium ripens its wall gradually decays away and the ascospores are finally set free by the rupture of the walls of the asci. The ascospores, it must be carefully observed, have not been formed as the direct result of conjugation No single cell corresponding to the zygote of other forms is clearly distinguishable; but the rapid growth that results in the formation of the cleistothecium must probably be regarded as due to some process of fertilization. A multicellular body is formed which in its turn gives rise to reproductive cells, the ascospores. These, however, need no fertilization, and are therefore true spores. The spores do not give rise directly to other bodies like those which bore them, but to ordinary hyphae, which must produce fresh gametes before more ascospores appear.

The more distant relatives of Mucor are so numerous that only a few of the best known can be mentioned here. Some have become adapted to a parasitic life on living

animals and plants. These for the most part send their hyphae deeply into the tissues of their host, and thence obtain their nourishment, while their reproductive organs

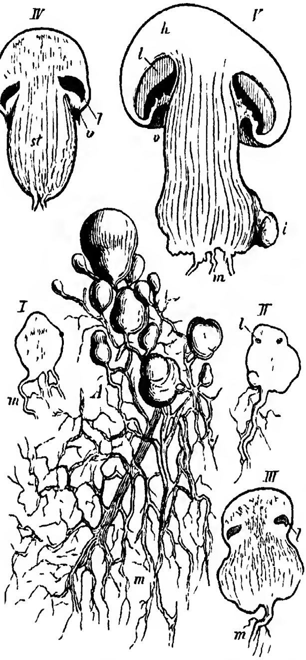


FIG. 27. I to V. Stages in the development of Agaricus (From Goebel)

m mycelium. *h.* pileus *l.* gill
v. velum *i.* bud *st* stalk.

alone appear upon the surface. Some such forms prey upon insects, ultimately causing their death. Others, among the best known of which are the rust and smut fungi, prey upon plants, causing discoloured spots on their

leaves or reproductive organs, as in the case of the smut of wheat. In many plants these fungi are extremely difficult to eradicate, for all visibly infected parts may be carefully picked off the plants, and yet the spots may appear again, even year after year, as the deep-lying mycelium retains its vitality and merely sends up fresh fructifications.

The common mushrooms and toadstools are among the most highly organized of the fungus group, and at first sight appear to have but little similarity to the more lowly organized moulds The part which here appears above ground is a large and highly developed spore-bearing organ; below, attaching it to the soil and drawing in nourishment from decaying animal or vegetable substance, is the mycelium The spore-bearing organs themselves are indeed only aggregates of upright hyphae, which cohere together as they grow, and then become differentiated from each other till they come to form the complicated mushroom structure. The spores in the mushroom are formed as little projections on the plates on the under side of the head and fall off as a brown dust when they are ripe.

Puff-balls essentially resemble mushrooms except that the spore-bearing tissue is differently arranged, and the spores are entirely enclosed, till they are ripe, in an outer case formed of coherent hyphae

Before we leave these lower plants altogether, we must notice one more group, the Lichens, so frequently to be seen on old walls, old trees, or weathered rocks. The usual colour of the Lichens is a greenish-grey, but they may be brilliantly coloured, yellow or orange. At first sight they appear to be Fungi, for the mass of the body is a mycelium sending attachment hyphae into or over the substratum upon which they occur, and giving rise to spores in the characteristic way. A little reflection, however, suggests the extreme improbability of any organism's being able to obtain adequate nutriment from old bricks or dry rocks; and a further investigation of the lichen reveals the presence, entangled among the hyphae, of numerous bright green cells. The green colour may readily be proved to be chlorophyll, and the cells may be

removed from the mycelium when they are seen to divide and grow quite independently. If spores of the Fungus be sown in company with the green cells, they germinate

FIG. 28. A lichen (From Sachs)

A. Part of a lichen
f attachment of the plant to the trunk of a tree.

B Algae cells attacked by lichen fungi
g alga *h* hypha

and send out hyphae in the ordinary way, but these hyphae at once attach themselves (Fig 28, A) to the green cells, branching over them, sending suckers into them,

and finally enclosing them in a dense network. The result of this association is, in fact, an ordinary lichen. It seems, therefore, that the lichen is a compound plant made up of an Alga and a Fungus, which live together either with one parasitic upon the other, or with both as partners in living processes As regards these two views it is obviously of advantage to the Fungus to be associated with another body, which can provide it with carbonaceous food it is supposed by many observers that the Alga similarly profits by receiving supplies of watery solutions from the Fungus, and by being protected from possible drought by a mycelial covering. In many cases, however, the dryness of the substratum renders it very doubtful whether the Fungus can obtain moisture for its associate, and recently emphasis has been laid upon the way in which the hyphae crowd over the algal cells, even penetrating their substance, and it has been pointed out that this is not to protect them, it is rather to prey upon them thus the Fungus is probably to be regarded as a parasite, and the Alga as its host. The lichen is, of course, in either case, really a compound plant.

CHAPTER IX

HYDRA

WHILE Spirogyra and Mucor may be taken as representative of the lower forms of vegetable life, the fresh water polyp Hydra is a good example of a simple multicellular animal. Even naked-eye observation shows, however, that in Hydra we are dealing with an organism of higher specialization than either Spirogyra or Mucor. The best way to observe its habits is to separate the Hydra from the green fresh-water weeds amongst which it lives, and put it into water in a small glass vessel, together with some of the minute water animals which can just be made out as moving specks among the weeds. After a time the Hydra will be found attached by one end to the surface of the glass with the thin cylindrical body crowned by its circle of fine tentacles stretching out into the water (Fig. 29, A). A jar given to the glass, a touch on any part of the animal itself, a disturbance in the water, may at any moment cause a sudden change of shape, the body becoming almost a ball and the tentacles mere knobs upon its surface (Fig. 29, B). Here is a power of quick response to outside conditions quite unlike anything observed in Spirogyra and Mucor. Again, it may happen that as the tentacles in the expanded condition wave to and fro in the water they may come into contact with some small animal Their very touch appears to paralyse the prey, and, as it lies motionless, the tentacles curve inwards over it, conveying it towards the mouth which lies in their midst.

So far Hydra has been spoken of as fixed, but though this is its habitual condition it is also capable of moving from place to place. Occasionally it may be seen to contract on one side only, bringing the body over in a curve till the tentacles touch the surface of the weed or glass, the further end of the body then lets go its hold, is brought nearer, takes hold again, and the tentacles

advance. In this way, something after the manner of a looper caterpillar, Hydra may progress fairly rapidly. Occasionally it moves in other ways, sometimes gliding over the surface of the weeds without appearing to let go its hold at the lower end of the body, sometimes crawling by means of its tentacles. It is incapable of swimming,

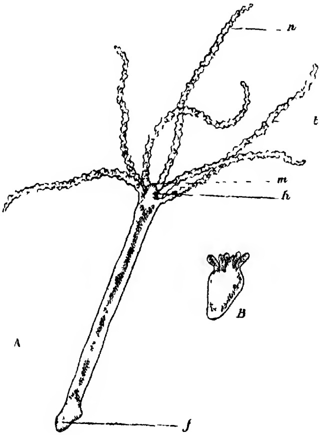


FIG. 29. Hydra.

A Expanded.
B. Retracted
f. foot
h. hypostome
m mouth.
n battery of nettle-cells.
t. tentacle

but when falling through the water may often be seen to hold the tentacles expanded outwards on all sides, the body thus falling very slowly like a tiny parachute. A strong lens or a low power of the microscope shows the different parts of the body more clearly, and to a certain extent the different cells can be made out by their help, even in a living Hydra. Thus the lower end, by which

the Hydra fixes itself, is seen to be thickened, and long narrow cells can be distinguished, contrasting with the much broader cells which form the outside of the body elsewhere. The mouth is a small opening raised on a little conical projection, the hypostome, lying centrally among the tentacles, and the movement of each tentacle can be studied in detail. In a state of complete expansion a tentacle is almost cylindrical with a slightly sinuous outline; as it contracts and thickens the outer layer of cells is thrown into close folds, the projecting cells of the expanded tentacle being brought close together. The mechanism, then, by means of which contraction takes place, obviously must lie below the surface of the body, which is merely passively crumpled by the process of shortening.

What is thus easily observed in any living Hydra is sufficient to show that there are differences among the cells, some performing one function and some another. Moreover, it is plain that distant cells can communicate with each other, so that one may receive a stimulus to which another responds, while, again, the simultaneous contraction of different parts of the body shows the existence of such a degree of organization among the different parts as to make possible their co-operation for the purposes of movement, nutrition, and so forth of the whole individual.

Further details of structure have been made out by sections, and by maceration which causes the individual cells to fall apart, and allows them to be studied separately under the microscope (Fig. 30). The whole body is nothing more complicated than a two-layered sac. The mouth leads into a wide space running the whole length of the body, but blind at the lower end, lined by a single layer of large cells with irregular outline, and, some of them, provided with flagella (Fig. 30, F). If these cells are isolated they are also often found to have one or more projections at the inner end, the protoplasm of which is different in appearance from that forming the whole body of the cell, a portion of it being specialized to form a little clear firm rod (Fig. 30, D). The rods possess in an especial degree the power of contracting, and have therefore caused the name of 'muscle processes' to be given to the portions of the cell in which they lie. They are disposed in a regular

manner, running round the body, so that as they contract the body grows narrower and consequently longer. The rest of the protoplasm in some of these cells is coarsely granular and vacuolated. Fat droplets and food granules of many kinds occur, and in *Hydra viridis* there are also rounded bodies coloured vivid green with chlorophyll. This whole layer of cells is known as the endoderm. It is separated from the outer layer, or ectoderm, by a thin supporting layer, known as the mesogloea, composed not of protoplasm, but of a kind of firm jelly secreted by the neighbouring cells.

The ectoderm is made up of several different kinds of cells, the most common of which are of a more or less cylindrical but somewhat irregular shape, prolonged at their inner ends into long processes like those of the endoderm, but running lengthwise along the body instead of round it (Fig. 30, A). When they become short and thick, therefore, the whole body is drawn together into a ball, and the rest of the layer is thrown into the deep folds already observed in the tentacles, when they become long and thin the whole body expands. Obviously some sort of correlation must exist between ectodermal and endodermal muscle-processes, when the former contract the latter must be in a state of expansion and vice versa.

Lying between the ordinary cells of the ectoderm are little groups of unspecialized rounded cells known as interstitial cells (Fig. 30, A, *i.c.*) Some of these develop into the nettle cells (Fig 30, C), which are found in numbers over almost the whole body, but occur in especial abundance on the tentacles. These have their protoplasm much reduced by the secretion within each of a little oval capsule containing a long, very fine thread, which normally lies rolled up inside it. If a tiny projection which can be seen on the outer surface of the cell be touched by any substance chemically irritating, such as a living animal that can be used for food, the thread is shot out with lightning rapidity, and to an amazing length as compared with the tiny capsule that previously held it. A little methyl green, or even beef-tea if fairly strong, run under the cover-slip will cause an explosion of the threads. A state of pressure seems to be set up in the fluid within the capsule which causes the thread to be turned inside

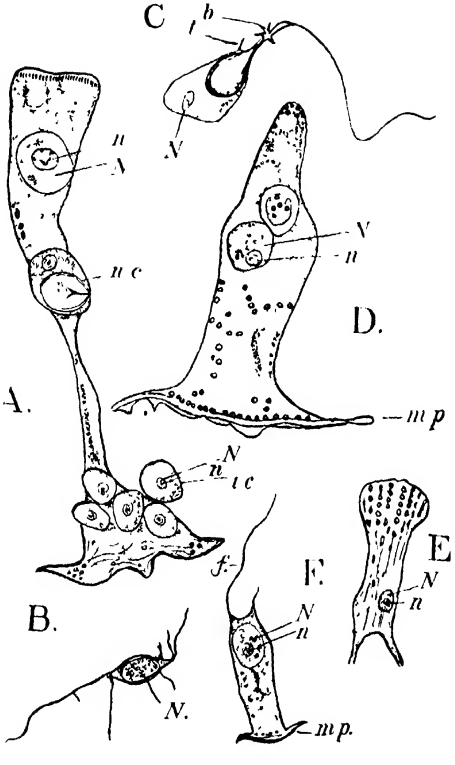


FIG 30 Cells of Hydra

A. Ectoderm cell and interstitial cells. B Nerve cell
C Nettle cell. D. Endoderm cell E Gland cell
F. Flagellate endoderm cell. *b* barbs *f* flagellum.
i.c. interstitial cells *m p* muscle processes. *N* nucleus.
n. nucleolus. *n c* nettle cell *t.* sensitive projection.

out, and thus to be thrust from the body. There are two kinds of threads, one, the larger, being thickened near the surface of the body and bearing strong recurved barbs on this portion, the other having no barbs. Already a serious organ of offence when numbers are thrown out together, the thread is made more formidable by the secretion of a poisonous fluid, by means of which Hydra can paralyse its prey and render it more easy of capture Once thrown out a thread cannot be withdrawn and is therefore useless, so that generally, after its expulsion, the whole capsule is discharged from the body, and new ones are continually being formed by specialization of the interstitial cells

Cells with long fine processes and a very small central mass of protoplasm (Fig 30, B) may be found in maceration preparations, sometimes attached by the end of one process to the inner end of a nettle-cell These are the nerve cells in which is specialized the power of transmitting stimuli, and which form a close network all over the body, just under the surface.

It only remains to describe the long narrow cells at the lower end of the body These resemble those of the endoderm in their coarsely granular contents, they are, in fact, gland-cells, whose protoplasm makes and exudes a sticky fluid, which enables the Hydra to attach itself to the surface of weeds, or of a glass.

Ectoderm, endoderm, and mesogloea can be recognized in the tentacles, the two first composed of cells like those of the same layer in the rest of the body, except that those of the endoderm are flatter, less regular in shape, and have less coarsely granular contents.

As already indicated, Hydra feeds upon tiny living animals, which it paralyses with its nettle cells and passes by means of its tentacles to its mouth The food is swallowed by contraction movements, and passes into the central cavity, where it is acted upon by fluids secreted by the living cells which line the cavity. Part of the food material thus becomes diffusible, part, which resists the action of digestive juices, is thrown out again through the mouth; part is taken into the cells by means of amoeboid processes, and digestion is completed within the cell-body. Transference of the digested material must now occur by

gradual diffusion from one cell to another, for every cell all over the body must repair its waste, while growth and cell-division also take place.

Though, as in all multicellular organisms, ordinary cell-division normally leads merely to the increased size of the body, and not to the appearance of a new individual, rapid proliferation of cells in one part of the body may result in the formation of a new Hydra, which grows as a kind of bud upon the parent polyp. Near the fixed end of the organism a small swelling arises by growth and cell-division of both ectoderm and endoderm in this region. The knob thus formed rapidly develops into a hollow outgrowth, tentacles grow out just behind the free end and a mouth breaks through into the digestive cavity, which is still in communication with that of the parent. At last the connexion becomes narrowed and the bud breaks away as a small but perfectly developed Hydra.

In every adult individual there are certain cells which have no definite part to play in the body, but are set aside for purposes of reproduction. Rapid division amongst the interstitial cells gives rise on the surface of the body to little swellings, the reproductive organs, which are of two kinds, known as ovaries and testes. In the ovary, borne near the lower end of the body, after division has proceeded for a certain length of time, one cell begins to grow at the expense of its neighbours, actually engulfing them by means of large amoeboid processes. The nourishment so obtained it stores up within itself as reserve material, which can be seen as large granules lying in the protoplasm. This is the ovum or egg-cell. In the testis, which arises higher up on the body of the same individual, division proceeds rapidly till a great number of minute cells have been formed. In each the protoplasm is reduced to a very fine layer, surrounding the nucleus, and a long contractile thread develops, by means of which it can lash itself through the water, when set free from the testis by the rupture of the wall. Each cell is known as a spermatozoon.

When the ovum is full grown the wall of the ovary bursts, exposing the ovum to the water. The spermatozoa pass through the water, come into contact with the ovum, and one completely fuses with it, giving rise to a single

cell corresponding to the zygote of Spirogyra or Mucor, but here known as the fertilized egg-cell. As would be expected, rapid division now takes place, and this results in the formation of a little single-layered oval embryo bearing but small likeness to the adult. By further cell-division the single-layered organism becomes double layered, and a digestive cavity and mouth appear, the latter surrounded by a circle of little hollow knobs, which, as they increase in length, are recognized as the tentacles.

While the form of the body has thus been shaped by a gradual and orderly growth, the different cells of which it is composed have pursued their own particular lines of development. At first almost alike, cells, even side by side, come after a time to take on different characters, one growing long fine processes which distinguish it as a nerve-cell, another gradually secreting within itself the complicated stinging capsule with its long coiled thread, till every part of the adult organism can be recognized.

The fundamental likeness between the method of reproduction by gametes and the conjugation described in earlier forms will readily be understood. The process consists essentially in the complete union of two cells, resulting in increased energy, as shown by rapid growth and division. In unicellular forms the fusion takes place necessarily between two entire individuals as in Vorticella, while in multicellular forms we find either, as in Spirogyra, that every cell is capable of conjugation, or, as in Hydra and Obelia, and to a lesser extent in Mucor, that certain cells are set apart for the purpose. This method has two results: firstly, any individual may be able to furnish a large supply of such cells, and so give rise to offspring, while still pursuing its own independent life; and secondly, the single-celled germ must go through a more or less complicated kind of development before it reaches the adult form. This implies, of course, in the case of such an organism as Hydra, that the gamete must carry in it the power of giving rise to cells unlike itself, but like those which formed the rest of the body of which it was once a part. The cell-division which takes place during development may be compared to that which follows conjugation in Vorticella, differing from it chiefly in that the resulting

cells are unlike, and remain united after division. Since the young offspring is, for a time, incomplete and incapable of supporting its own life, having no power to capture food, or indeed to digest it if captured, it is natural that we should find, as in Hydra, that provision is made for this period in a store of prepared food material Such a store, however, implies a large and bulky cell, and thus militates against ease of movement. Hence a very natural differentiation of function has taken place in the gametes one cell remaining motionless and storing within itself all the food reserves; while the other, consisting of little besides a nucleus, has developed a lashing tail and has its protoplasm specialized for the purpose of locomotion. Thus it comes about that there are no longer two like gametes, but two unlike, and for a union of such, the term fertilization is usually employed instead of conjugation It is interesting to notice that a differentiation, in some respects very similar to that described here, obtains between the two conjugating individuals of Vorticella. In this case, the differentiation has almost certainly arisen in connexion with the stationary habit, and the importance of the motile microgamete is obvious

That like begets like, that offspring resembles parent, not only in the broad features in which all members of a race are alike, but even in tiny personal details, is a common fact of ordinary observation How the complicated processes of development proceed that ultimately the cells may be differentiated in this or that particular way, so that a Hydra is formed and not another polyp, so that this individual comes into being and not that, forms one of the most fundamental problems of Biology, and one of which at present no full or satisfactory explanation can be given. Obviously, each single-celled germ must carry in its minute physical structure certain definite latent possibilities of development, which it receives or inherits from the parent, but of the exact way in which these possibilities are stored, and how they work themselves out in the course of development, we are at present completely in ignorance, while the part which varying external conditions can play in modifying or selecting among different inherited tendencies is still much under discussion It may be noticed in passing

that as the union of cells from two distinct individuals is necessary for the production of the single-celled germ, it is probable that varying and mutually exclusive possibilities exist in the fertilized egg; which of these possibilities find fulfilment must depend, therefore, not only on the minute structure of the zygote, but also on the external conditions.

CHAPTER X

OBELIA

WHEN Hydra reproduces by budding, the buds rarely retain their attachment to the parent; in allied forms, however, the connexion persists, and is such that not only the body-walls, but also the central cavities, are in free communication. In many cases the budding is very vigorous, and so colonies of polyps arise, with the individuals sometimes close together, sometimes separated by long stalks. Where such stalks are present, and regularly arranged, a branching like that of plants results and the whole colony may be, and has been, mistaken for a vegetable growth. Obelia is one of these plant-like colonies. It grows upon sea-weeds, or upon the wooden supports of piers or breakwaters, and is attached to such foreign bodies by means of closely adherent root-like 'runners'. From these runners, 'branches' grow upwards to a height of a centimetre or more; to the naked eye they appear as fine whitish branched threads, each thread showing little lumps at fairly regular intervals on alternate sides. Examined with a lens, the lumps are seen to be the polyps; they are united by long stalks, and the whole colony grows in a sort of zigzag, for the oldest polyp is at the end of any given branch, and the young ones arise below it, but upon alternate sides of the stalk, to form the terminal points of other branches. The terminal polyps, or hydranths (Fig. 31, A, *h*), resemble Hydra in all essential respects; but Obelia is polymorphic (see p. 21), and polyps of a second kind, the gonangia (*g*) are found in the axils of the branches; these are much reduced, and serve the purpose of reproduction only. The whole colony is invested by a chitinous layer, the perisarc, secreted by the ectoderm; it follows the outline of the soft tissues and forms thin tubes over the stalks, widely open cups over the hydranths, and barrel-shaped

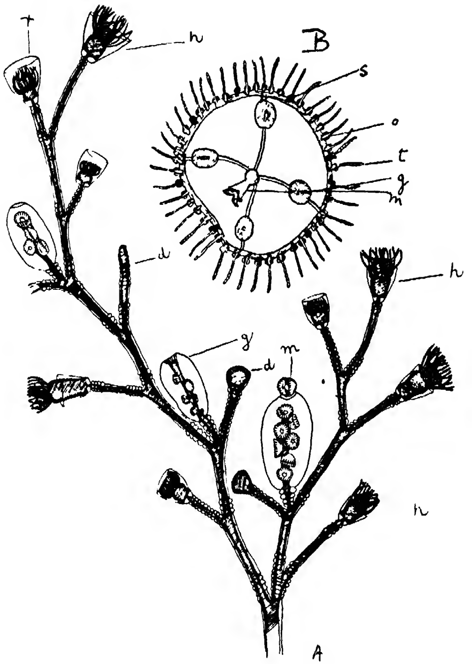


FIG 31. Obelia A. Part of a colony. B. Medusa

d developing hydranth
g. gonad (in B).
g gonangium (in A).
h. expanded hydranth.
m. manubrium (in B).
m. medusa escaping from gonangium (in A).
o ocellus
r. retracted hydranth
s statocyst
t tentacle

coverings to the gonangia It stands away from the soft tissues in the adult polyp, retaining its original attachment only at scattered spots. The hydranths, which, like Hydra, are very contractile, are withdrawn into the cups on irritation. Just below the hydranths, and above the attachment of the lateral branches of the main axis, the perisarc is thrown into folds, which gives these regions a ringed appearance

The hydranth is short and cylindrical, and rounded off at the free end to form the globular hypostome which, as compared with that of Hydra, is very large it is constricted to a little waist at its junction with the rest of the body, so that the central cavity comes to consist really of two compartments communicating by a narrow passage. The tentacles, springing from the base of the hypostome, where the body widens out, number as many as twenty or more, and are solid the cavity is completely obliterated by a single row of large endoderm cells As in Hydra, the ectoderm is flattened, and is richly supplied with nettle cells At the fixed end the body narrows suddenly to form the stalk, which is perforated by a tubular extension of the central cavity, thus the cavities of all the members of a colony are put in communication New hydranths are budded off from the stems just below the old ones.

Within the chitinous covering of the gonangium is a stoutish rod of soft tissue, called the blastostyle It is really a reduced hydranth tentacles, hypostome, mouth, have all disappeared, the central cavity persists as a narrow tube, but it ends blindly, and the free end of the blastostyle is widened out and in contact with the top of its chitinous case. Upon the outside of the blastostyle numbers of buds arise, each enlarges and flattens out to become like a little umbrella with a short handle, or a saucer with a process projecting from the middle of the concave side The buds are attached to the blastostyle by the convex side, and when they have developed so far, this rod begins to shrink away from its perisarcal case, and in fact to become altogether small and dwindled At the same time the buds, which are now known as medusae (Fig. 31, A *m*., B) break away from their attachment, and move towards the apex of the

case, where an aperture appears, through which they escape into the water. The medusae swim about by contractions of the margin of the umbrella, which is downwards in the water, the convex side being upwards. Sometimes the umbrella turns inside out, so that what was convex is now concave, but it still faces upwards. The margin of the umbrella is fringed round with tentacles (Fig. 31, B, *t*), and at the base of each there is a patch of specialized ectoderm known as an ocellus (B, *o*). In a similar position, on each of eight tentacles at regular distances apart, is another specialized patch, having the form of a minute vesicle, with hair-like processes projecting from its living cells into its cavity these vesicles are called statocysts (B, *s*) It will be remembered that irritability, the power of response to stimulus, is one of the chief characteristics of protoplasm, and sensitiveness to light and touch at least is a property of unicellular forms. In Hydra also we noticed the shrinking back of the animal when jarred, but, as in the simpler forms, it was not apparent that any one part of the body was more sensitive than another. In higher organisms there is an increase in sensitiveness, and also in its localization in some particular part or parts of the body In most animals there is special apparatus for the appreciation of what goes on in the outside world, or, indeed, in the organism itself, it consists of sense organs and a centralized nervous system, which are connected by means of nerves, or nerve-fibres. It is the sense organs which receive the stimuli, impressions of light, heat, sound, and so on, but it is the central nervous system alone which controls the response to the stimuli. The ocelli and statocysts are the sense organs of the medusa, and, as we shall see later, are connected with a special circle of nerve-cells which lies beneath them and may be regarded in some respects as analogous with the central system of higher forms. The ocelli are probably sensitive to light; the statocysts seem to be affected by vibrations of the water, and so to give the organism impressions about its position and balance, and the direction in which it is moving.

The process which depends from the middle of the concave side of the umbrella is called the manubrium (Fig 31, B, *m*), and bears the mouth at its tip. The mouth opens into a narrow tube which leads into a squarish central cavity,

tubes radiate from the angles of this cavity towards the margin, where there is a circular canal. Rounded bodies hang down, one from each radial canal, into the space beneath the umbrella. These are the reproductive organs, or gonads (Fig 31, B, *g*), and contain either ova or spermatozoa . they arise within the canals and form outpushings of the entire body-wall of the ectoderm, as well as of the endodermal lining of the canals

The external surface of the medusa is covered with ectoderm, just as is that of the hydranth or Hydra , the internal cavities of both are lined with endoderm, and between these there is a layer of mesogloea. The arrangement of layers is therefore the same in both kinds of polyps ; and it is easy to see how the one may have been derived from the other The difference lies in the great development of mesogloea in the medusa, in what corresponds to the base of the hydroid Such a development, not only in thickness, but also in area, would evidently give to the base the form of a wide expansion, and might easily involve the body-wall, so that the tentacles would come to surround the margin of the expansion, and the hypostome be pulled out also Then, by the elongation of the tip of the hypostome, the figure of the medusoid would be completed. The increase in the bulk of the mesogloea causes also a forcing together of the layers of endoderm to form a single sheet, known as the endodermal lamella. There are left, however, the radial canals, the circular canal, and the small central cavity to represent the large central cavity of the hydroid

The cells composing both forms are alike, and may be studied, as were those of Hydra, by means of sections or by maceration preparations. The ectoderm consists for the most part of flattened epithelial cells, and immediately below these are fusiform contractile cells, so that the complex ectoderm-cells of Hydra seem to be split up here into an external epithelial layer and a deeper-lying muscular tissue, in which the length of the cells runs round the body. There is a special development of this muscular tissue round the margin of the umbrella ; in the sub-umbrella and manubrium the simpler state of things persists. There is again a loose network of nerve-cells, but in Obelia it is found in the mesogloea. It is

especially well-marked in the medusa, where, like the muscle-cells, it forms a concentration near the margin, doubtless in connexion with the presence of the sense organs. Nettle cells are scattered freely over the surface of the body. Like the ectoderm cells those of the endoderm have lost their muscular processes, which are represented by independent fibrous cells, lying in or upon the meso-gloea. The true endoderm-cells, which form the endodermal lamella and line the canals, are simple and rather cubical in shape, and are probably concerned only with the digestion, absorption, and distribution of food.

We have seen how the colony is built up, how it enlarges only by budding. Nutritive polyps of an ordinary hydroid form arise at the bases of old hydranths, and reproductive polyps of a reduced hydroid form come in the axils of the older branches, but in both cases no specialized and separate cells are concerned in the formation each arises as a simple outgrowth from the colony-wall. While new members of a colony, however, always begin life as buds, new colonies are only started from single cells formed by the conjugation of two unlike gametes; and these gametes are borne by special members of the colony, the free-swimming medusae. The gametes, or ova and spermatozoa, which, as we noticed, are formed in special organs or gonads, are lodged in different medusae. They are all shed into the water, and one spermatozoon conjugates with one ovum As a result of division in the fertilized egg-cell, a tiny free-swimming organism, quite unlike either hydranth or medusa, is formed This is known as a planula, and is an oval body covered with cilia, by the vibrations of which it moves rapidly through the water. The body consists of two layers of cells, and is at first solid, but as time goes on a split appears in the central mass. This will be the central cavity of the adult, and the cells bounding it will constitute the endoderm, while the external cells are the future ectoderm. The planula fixes itself after a time to a bit of sea-weed, or a sea-bathed pile, loses its cilia, and gradually assumes the form of an ordinary hydranth. Processes grow out over the sea-weed or pile, and from these are budded off other hydranths. The hydranths develop stems, the stems give off buds, and so the new colony is established.

The occurrence of the free-swimming stage in the life-history of this animal is interesting. We noticed, in connexion with Vorticella, that a free-swimming form would ensure a scattering of the species, and hence would be useful to prevent the overcrowding of an area by fixed organisms. In Obelia, as well as a motile adult form, the medusa, we have the young developing organism regularly passing through an active stage. It seems possible, therefore, that some other purpose besides the prevention of overcrowding may be served here It is evident that if an animal escapes from the egg at an early stage of development and leads a free life, it will be able to obtain food for itself, and therefore large stores of nutriment will not be needed within the egg Thus the energies of the parent can be devoted to the formation of more reproductive cells, and this will give opportunity for great increase in the numbers of a species. Such free-swimming young forms are known as larvae, and among the lower animals, where very many individuals are killed, usually serving as food for other animals, their occurrence is very common. It must be remembered, however, that while it is so advantageous to a species to have its numbers increased by the introduction of larval forms, it is by no means good for the individual A given individual will stand a much greater chance of living and thriving if it is protected by egg-coverings until it is fully formed than if it is let loose upon the world to fend for itself in an immature state.

CHAPTER XI

SOME FORMS ALLIED TO HYDRA AND OBELIA

COLONIES very similar to Obelia, though varying considerably in structure and manner of branching, are found attached to water-weeds or rocks, frequently in the sea but exceptionally in fresh water. The colonies may be clothed with a chitinous perisarc, or they may be destitute of any covering The hydroid polyps may be all of one type, or they may exhibit a high degree of polymorphism, showing, besides the nutritive and reproductive forms, others which are little more than bunches of tentacles. The medusoids may, as in Obelia, be free-swimming, or they may remain attached throughout life to the colony. Sometimes they are not only attached, with their central cavities in communication with the canal system of the colony, but have lost their mouths, so that they are reproductive individuals only, with no possibility of feeding for themselves. Not only the mouth, but tentacles also, umbrella, central cavity itself, may be suppressed, and then the medusa is represented only by a sac of ova or spermatozoa. It has been suggested that the ovaries and testes of Hydra may really be much reduced medusae.

The jelly-fish which are found swimming freely round our coasts are medusae. Many of them have been shed from a colony like Obelia, but the larger ones are quite independent, and form a group by themselves. These may attain a size of as much as a metre in diameter, and then little fish are found to take shelter under the umbrella. They are often very brightly coloured; and in some forms there is a considerable development of nettle cells, which may become unpleasantly manifest to people swimming in their neighbourhood. These medusae may have a direct development, i.e. the planula may just turn into the adult form, or it may develop into a small and very simple stock which bears some resemblance to a hydranth, and

from this the medusae are constricted off, the stock dying away as soon as they are detached.

Colonial forms are also known which are free-swimming instead of fixed. These all inhabit the surface-waters of the open seas, though they may be driven by winds or currents up to the coasts. The colony may have an almost plant-like appearance owing to the arrangement of its

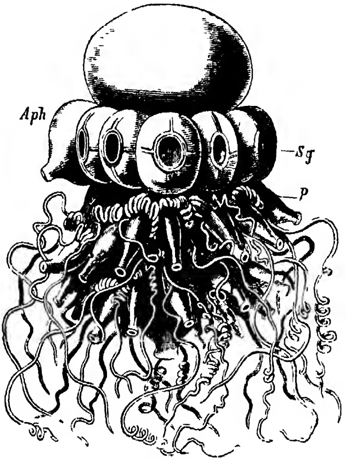


FIG. 32 *Stephalia corona* (From Sedgwick)
Aph air-bell. *Sq.* swimming-bell *P* nutritive polyp

members regularly about a long central stalk, which may depend for a considerable distance into the water, or it may be compact and bear some resemblance to a medusa, the members hanging from the cover side of an umbrella-like expansion (Fig. 32) The colonies show an extreme case of polymorphism, each member having become so specialized and modified in structure for the performance of some special bit of work as often to make it impossible to determine whether it is really to be regarded as corresponding

to a whole polyp or merely to some part. Some of these doubtful members feed for the whole community; others propel it through the water; yet others perform the work of a tentacle only; while one or more at the apex of the colony act as air-sacs and regulate the depth at which the whole shall float. It is these air-sacs which form the flattened expansions referred to above, and give to some

FIG. 33. Branch of a Madrepore, *Amphihelia oculata*, showing expanded polyps (From Lacaze Duthiers)

of the colonies a superficial resemblance to a medusa (Portuguese man-of-war, &c.).

The Corals form a great group of fixed forms. They protect and support themselves by the secretion of a hard, and more or less massive skeleton, or rather shell, for it is formed entirely on the outside of the animal, just as is the perisarc in Obelia. The different groups known popularly as corals are not all nearly related some of them are widely different in the arrangement of their soft tissues. Even when, however, they are most divergent, they have, by the adoption of the same kind of

life, become adapted in the same manner to its special conditions, and hence exhibit a strong superficial similarity. In one group, the Hydrocorallines, the polyps which project from the tiny holes in the massive calcareous skeleton are really hydroids. The true corals or Madrepores belong to a different set, the Anthozooids, which are represented in simpler form by the well-known sea-anemone The anemone is solitary and has no shell; but many non-colonial kinds with the characteristic coral cup are also found upon our coasts. The coral polyps differ from Hydra in certain important points of structure. For instance, there is no hypostome, and a sort of 'throat' is formed by a tucking-in of the ectoderm, so that it looks as if the hypostome had been pushed into the body, with the result that the true mouth has come to lie at the inner end of the 'throat'. Then a number of plate-like projections, called mesenteries, extend from the body-wall into the central cavity. These mesenteries must not be confused with the hard 'septa' which may be seen in the dried skeletons as delicate radial projections into the cavity of the cup where the polyp was lodged The mesenteries are entirely soft and arise from the inner tissues of the polyp; the septa are hard, and, like all the hard parts, are formed on the outside of the body, as they grow up into the cup they push the soft body-wall before them, and this grows too, in order to cover them Again, upon the free edges of the mesenteries are to be found longitudinal thickenings, the mesenterial filaments, they assist either in respiration or digestion, or both. The skeletons or shells present various forms. some, like those of the Hydrocorallines, are massive, others are simply branched, and yet others display most fine and beautiful tracery. In Hydrocorallines and Madrepores alike the shell is a secretion solely of the ectoderm cells, which obtain the lime-salts for its formation from the sea-water it is formed entirely upon the outside of the colony, just as is the horny shell in Obelia, and the massive branches in the one case correspond to the slender stalks in the other. These corals are sometimes known as reef-building corals, for to their growth is due the presence of the vast coral reefs of southern seas.

There is yet another group of corals to be noted, of which the precious coral of commerce may be taken as

an example. This red coral forms extensive banks, but does not enter into the composition of reefs, though some of its relatives do (Tubipora). The hard parts here are formed of compressed masses of tiny spicules secreted always by ectoderm cells, which, however, have broken

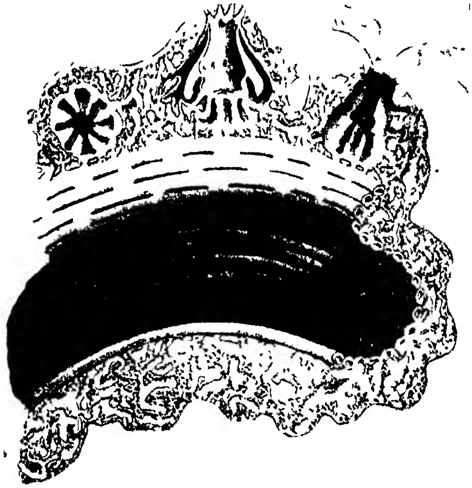


FIG 34. Part of a branch of *Corallium rubrum* The soft tissues are removed from the solid core and turned back, showing the canals of the soft tissue within, and the polyps cut in various directions above. (From Lacaze Duthiers)

away from their fellows and wandered into the mesogloea. The skeleton is, therefore, an internal structure, although formed as much as that of a Madrepore by external cells. The spicules fit accurately into one another or are welded together by a cementing substance, and in the red coral form a solid rod which runs up the middle of the colony. Those parts in which active growth is going on are covered

with soft tissue, and the polyps are embedded in this. The precious coral comes chiefly from Italy and Japan, but upon our own beaches, clumsy-looking leathery lumps of an allied form, called 'dead men's fingers,' are found. The whole mass is riddled with tubes, and into these the polyps, which project all over the surface, may be

FIG 35. *Muricea chamaeleon*, a gorgonid (From von Koch.)

withdrawn: scattered though its substance are numbers of isolated spicules of the same kind as those which form the solid core of the beautiful precious coral.

In some forms the skeleton consists chiefly or entirely of a horny substance; this may be strengthened by lime-salts, sometimes in the form of spicules, sometimes as granules, but occasionally the horny substance is the only

supporting material. Carbonate of lime may be present in such quantity as to render the skeleton hard and rigid, but usually the amount is not so great, and the colony is entirely flexible. Often its build is light and its branching luxuriant, so that most graceful traceries result (Gorgonia), or it may be more compact, and form flattened expansions of a feather-like or leaf-like appearance (sea-pen, Renilla, &c.)

Many members of this group, and also many of the free-swimming colonies (see above) exhibit the beautiful luminous effects known as phosphorescence

When we think of the flower-like appearance of polyps with their brilliant colouring and their waving tentacles, of the tree-like growth of the colonies resulting from their budding, and of their much-branched form, we cannot be surprised that the earlier Biologists were greatly puzzled as to whether the organisms which have just been described should be regarded as plants or animals It was not, indeed, until towards the end of the eighteenth century that their animal nature was fully established, and it is interesting to note that the name "zoophyte", which is often used now in a popular sense, was given to polyps as a sort of compromise, and in the belief that they were partly plants, partly animals

CHAPTER XII

DISTINCTIONS BETWEEN PLANTS AND ANIMALS

DURING the last century the researches of Biologists into the minute structure and intimate working of living bodies have revealed with increasing clearness the fundamental similarity of the life-processes of all organisms, however unlike in their outward form, or in their apparent activity, or want of activity. The work already referred to in Chapter VI, which was begun by Schleiden, Schwann, and others in the first half of the nineteenth century, has been carried on by a host of later investigators, who, while modifying many of the conceptions held by their predecessors, have shown that in the behaviour of the nucleus in cell-division, in the interaction of nucleus and cell-body for purposes of nutrition, and in many other processes which form the very basis of the vital activity of the body, the cells in all organisms are essentially alike. Nevertheless, while fundamentally alike in the possession of similar living substance, with similar powers of metabolism, growth, and reproduction, the mere superficial unlikeness between the tree and the birds on its branches remains as obvious as ever, and the existence of the difference demands some explanation.

Among lower forms of life, while in most cases there is no difficulty in deciding whether a given organism should be called a plant or an animal, yet many of the most striking contrasts between higher plants and higher animals are altogether absent. Such a contrast, for instance, as that between the compact body of the bird and the very diffuse body of the tree, or, again, that between the rooted immovability of the tree and the ceaseless activity of the animal, is wholly inapplicable when we consider a Spirogyra plant and a colony of coral polyps In Part I it has been shown how among unicellular organisms the dividing line between the two groups fades out altogether, and how, on the whole, among these simplest forms the only clearly

defined characteristics by which we may distinguish between a unicellular plant and a unicellular animal are the presence of a cell-wall with the consequent absorption of food material as a watery solution, on the one hand, and the absence of a cell-wall with power to digest solid food on the other. Here we have the simple fundamental differences which have set the two groups on widely diverging lines of development, and other differences follow. The solutions of food material which a plant needs will naturally be diffused through the water, and ability to move quickly from place to place will be of no immediate advantage. Animals, on the other hand, which are dependent for their food on their ability to ingest solid material, must in most cases possess the power actively to pursue their prey. Again, if a plant cannot go in search of food, it is of the utmost importance that it should be in touch with as large as possible an area where food may be obtained. Thus in Spirogyra the cells are set end to end in a chain, each cell exposing the larger part of its surface to the water, an arrangement unknown among the lower animals. The diffuse body of a tree, with its much-branched root and trunk, and its spreading leaves, gives a more complete response to the same need On the other hand, if an animal is to move rapidly from place to place, a compact instead of a spreading body is as obviously an advantage. It is interesting in this connexion to refer back to the modifications which take place when an animal becomes plant-like in its mode of life, by rooting itself in one spot, as do the Corals and the Hydrozoids (p 82). The formation of colonies, each like a miniature tree, is obviously a response to the same need as that of the plant to be in touch with a large area, and thereby increase the available food supply.

The power possessed by green plants of using inorganic materials for food renders their presence, except in special circumstances, essential to the existence of animal life in the world, for, were it not for the constant conversion of inorganic into organic material, which takes place in the plant body, the food supply would necessarily run short and life would soon become extinct. Again, green plants living on dry land purify the air from carbon dioxide, the waste of their own respiration as well as that of animals,

using the carbon dioxide for food as aquatic forms use that which is dissolved in water (see Spirogyra, p. 45), and restoring oxygen to the atmosphere It follows that without green plants the air would soon become unfit for respiration, owing to the accumulation of carbon dioxide in the place of oxygen, whereas by their agency the relative proportion of these gases in the atmosphere is kept fairly constant, and fresh organic food is formed out of actual waste material (see p. 26) This dependence of animals on plants explains the necessity of keeping a due amount of water-weed in aquaria, and also the movement which is being made at present to plant trees in the most thickly populated parts of our big cities.

There is still a further result of the different kinds of nutrition characteristic of the two groups. The activity of plants renders available to animals not only a constant food supply, but also a constant source of energy. It has been pointed out (p. 6) that complex organic molecules involve more energy in their formation than do simple inorganic molecules like those of carbon dioxide and water. Thus, in building the complex material out of the simple, energy derived from sunlight is used by plants and stored in their bodies to be set free when these complex materials, having been used as food by the animal, are broken up again in its body into the simpler substances.

The typical differences between plants and animals which have just been indicated, have set the groups upon widely diverging lines of evolution. Having from the outset different needs, it is obvious that, as animals are more and more perfectly adapted to respond to external conditions, they should differ more and more completely from plants which are being specialized along other lines. Hence it becomes more convenient from this point to deal with plants and animals quite separately.

In each case we have for the future to deal with multicellular bodies only, and in both groups an increasing degree of complexity is to be observed. In the lowhest multicellular forms, such as Spirogyra, all the cells are capable of performing all the operations necessary for life. A little higher, as in Hydra, and to a less extent in Mucor, the cells have gained the power of doing, some one thing, some another, especially well; but every gain

on one side means loss on another. For example, the power of contractility of protoplasm is present in a higher degree in the ectodermal muscle-processes of Hydra than in any part of the body of Amoeba, but these processes have no power of secreting digestive juices. Thus as they do their one kind of work with greater efficiency they become more and more dependent on other cells for the results of other necessary activities. While for the individual cell, however, loss of power takes place side by side with gain, the body as a whole becomes more unified, more efficient, more varied in its activities; in a dog's body the cells are still more specialized, still more interdependent, than they are in Hydra, while the body as a whole possesses incomparably more complete and varied powers of response to its environment. So it comes about that the high or low degree of organization of an animal or plant is judged by the degree of specialization of the parts and the completeness of their dependence on the whole, and this specialization will be traced through the descriptions which follow, and found in increasing degree, reaching its highest level in the vertebrate animals and flowering plants.

PART III

HIGHER ANIMALS AND PLANTS

CHAPTER XIII

THE EARTHWORM (*Lumbricus terrestris*) AND ITS ALLIES

THE higher animals, as contrasted with Hydra, exhibit a greater complexity of organs, a greater specialization of cells. The outside of the body is covered by an ectodermal layer, and there is a cavity inside lined with nutritive cells so far the conditions resemble those found in Hydra, but there the similarity stops In Hydra, there is, between these layers, a structureless mesogloea only in the higher animals, the body-wall and the wall of the inner tube (now serving simply as a digestive tract) are provided with layers of muscle which should perhaps be regarded as amplifications of the muscle-cells of Obelia, and they are further separated so as to leave a space, or body-cavity, for the inclusion of various organs for excretion, reproduction, &c. In most of the higher animals the reproductive organs are specializations of the wall of this body-cavity, or coelom, as it is then called. In the earthworm, the form to be considered now, the coelom is broken up into a series of compartments separated by membranous partitions the partitions correspond in position with the grooves on the outside which are so marked a character of this animal.

The earthworm is an elongate animal, with a soft flexible body. A 'head' and a 'tail' end may be recognized, also a dorsal and a ventral surface, but the two sides of the body are alike, so that if a cut were made through the middle line of the dorsal surface, the worm would be divided into exactly similar halves Symmetry of this kind is known as 'bilateral', and contrasts with the 'radial' arrangement in Hydra, where the body may be

cut longitudinally (i.e. through hypostome and basal disc) in many planes, and yet give similar halves. The worm attains a length of about 15 centimetres, and is cylindrical in form, though slightly flattened at the blunt posterior end, while the anterior extremity is somewhat pointed.

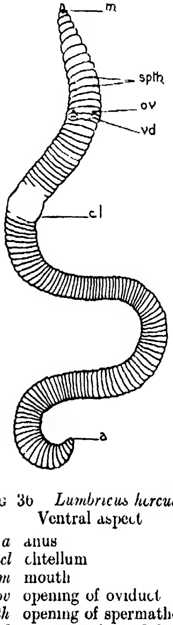


FIG 36 *Lumbricus herculeus* Ventral aspect

a anus
cl clitellum
m mouth
ov opening of oviduct
spth opening of spermatheca.
v d aperture of vas deferens.

The body is composed of about 150 similar segments, indications of which are shown externally as transverse grooves many of the internal organs are repeated in the great majority of the segments, and here again we have a sharp contrast to the body of Hydra which shows no trace of such repetition either without or within The most anterior portion of the worm is not a segment, but a lobe, the prostomium, which divides the true first segment, or peristomium, dorsally and abuts upon the second It may be retracted within the peristomium, and the mouth lies ventrally at its base the anus is oval and is situated at the extreme termination of the body. A short distance back, the integument is thickened upon the dorsal and lateral aspects of about five segments. This thickening is popularly supposed to mark the joining up of a worm which has been cut in two : it is, however, really a glandular region of the skin, the clitellum, and its cells secrete mucus for the formation of a cocoon in which the eggs may be laid. If a finger be drawn forwards along the side of the worm, a certain roughness will be felt : this is due to the presence of bristles or chaetae which are arranged in four pairs on the ventral half of every segment from the second to the last but one. The chaetae are curved

spines, wider towards the middle than at the ends, and made of chitin they serve as the locomotor organs, and are a prominent feature of the earthworm and its relatives, which are hence called Chaetopods.

There are several openings to be noted upon the surface of the body, besides those of the digestive tract. All along the mid-dorsal line is a row of pores lying in the grooves between the segments, from that between x and xi backwards, these are the dorsal pores which communicate with the body-cavity. Again, every segment, with the exception of the first three and the last, shows laterally, between the pairs of chaetae, other pores, the openings of the excretory organs Yet again, the orifices of the reproductive glands are to be seen upon segments xiv and xv, one pair on each, those upon xv being the more conspicuous as they have swollen margins There are, further, two pairs of pores between segments ix and x, and x and xi They lead into small cavities, the spermathecae, which have no communication with the interior of the body, their function will be noticed later on.

As its name indicates, the earthworm lives in earth, burrowing into it and feeding upon it, or at least upon the organic fragments occurring in it These worms eat various vegetable matters, such as leaves, especially fallen and decaying ones, succulent stems and so on, as also animal food, even their dead brethren, and they swallow large quantities of earth for the sake of the organic material contained in it. The earth passes through the body unchanged, but for being bound together by a viscid secretion from the digestive tract and for having the nutritive parts retained by the animal. This earth is heaped in coils, known as castings, in the near neighbourhood of the mouths of the burrows Owing to this habit the worm is a great aid to the gardener and the farmer, for by its means the soil is well turned over, earth from below being brought to the surface and giving a new layer of mould for crops. The burrows themselves usually occur in the soil or the subsoil, never at a depth greater than six or seven feet, and usually at a foot to a foot and a half. The worm excavates, partly by swallowing the earth which it wishes to remove, and ejecting it through the anus, partly by pushing it aside with the anterior end of the

body, of which the segments are somewhat telescoped, so as to offer a greater resistance. The burrow is lined with a sort of cement made of fine mould mixed with a viscid secretion from the worm, so that the walls are smooth and even, and often there is a lining of fallen leaves, which prevents the cold earth from touching the inmate's body. During cold or drought the worm inhabits the lower levels of the burrow (which usually terminates in quite a large chamber), and does not come to the surface at all. In damp weather, however, it lies during the daytime in the upper part of the hole, with the prostomium close to the opening, which is partially concealed by leaves, twigs and castings—a convenient position for the birds which prey upon it. At night the worm comes out of the burrow, either entirely out to wander about freely, or with the posterior end anchored, as it were, in the mouth of the hole, while the rest of the body moves in a circle round When disturbed in any way in this position, the worm darts back instantly, and is lost to sight in the hole The animal glides along by alternate elongations and contractions of its body, assisted by the chaetae, which constitute points of support It is very flexible, and even in the burrows can turn easily upon itself

The body of the earthworm is soft, it is of a lightish hue, sometimes almost white underneath, but dark brown upon the back, which is marked with a longitudinal line, the dorsal blood-vessel showing through the body-wall. The worm feels damp or even 'slimy' to the touch the slime or mucus is secreted by gland-cells of the body-wall, which are specially numerous upon the clitellum A delicate cuticle, chitinous, but very thin and soft, is secreted by other gland-cells all over the body, it has an iridescent appearance, and may easily be stripped from a worm which has been soaked in water The chaetae are derived from this cuticle the cells secreting them form deep sacs sunk in the body-wall, so that the bristles seem to spring from the underlying tissues, but they really belong to the most superficial layer or epidermis There are two sets of muscles in the wall longitudinal sheets whose contractions make the worm shorter and thicker, and circular fibres to cause its elongation.

All the internal organs project into the coelom this

cavity contains a liquid which seems to moisten and disinfect the outside of the body, for it exudes through the dorsal pores and washes away possible dust or grit from the skin. The surface soil in which the earthworm lives teems with minute organisms of all kinds, many of them injurious, and of course they get on to the worm's skin. The coelomic fluid washes some of them off with the dust, and for the rest, the amoeboid cells which are present in the fluid

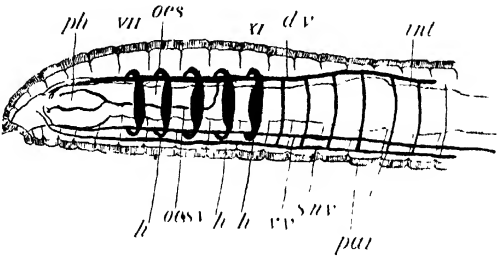


FIG 37 Digestive tract and vascular system

dv	dorsal vessel.	*pai*	parietal vessel
oes	oesophagus	*ph*	pharynx
oes v	oesophageal vessel	*sn v*	subneural vessel
h.	hearts	*v v*	ventral vessel
int.	intestine		

escape with it, and are able to ingest them, and so protect the worm from their encroaches.

The digestive tract, or alimentary canal, is a straight tube running the whole length of the animal. The mouth, as already noticed, lies in the first segment at the base of the prostomium It has neither jaws nor teeth, but is provided with soft lips and opens into a small buccal cavity, which in its turn leads back to the pharynx This region is muscular, with thick walls, and is attached to the body-wall by strands of muscle, but it is at the same time capable of being moved forwards, and doubtless assists in the prehension of food, which is often taken in by suction. A digestive secretion, derived from gland-

cells of the buccal cavity, is poured over leaves and sucl matters before they are eaten, so that they are partially digested, or at least prepared for digestion, outside the body. At the beginning of segment vi the pharynx gives plac to the oesophagus (Fig. 37, *oes*), a straight narrow tu running through eight or nine segments. In segment x it gives off a pair of short pouches or diverticula, ana in xi and xii it shows the apertures of the oesophageal glands. These are pouches of the glandular wall and secrete a milky calcareous liquid which neutralizes the acids in the vegetable matters upon which the worm feeds, for its digestive fluids have an alkaline reaction, and their activity is arrested by the presence of acids The oesophagus is followed by the crop, a thin walled dilation of the canal, which opens into a thick walled muscular gizzard The gizzard is furnished witl a chitinous lining raised into hard ridges, and thes with small stones which have been swallowed, grind t food and mix it with digestive juices until it becom a liquid. Behind the gizzard, i e. from about segment x: the intestine (*int.*) runs back to the anus it is thir walled and somewhat pouched, and its dorsal wall i tucked in to form a much-folded median ridge, the typhlc sole, which projects into its cavity. In Hydra, the digeste food is passed by simple transfusion direct from the central cavity to the various cells of which the body is composed. In more complicated animals, the food passes in the same way into the walls of the digestive tract, but it is easy to see that there must be some definite means of carrying it to the other organs, as they are often separated by wid spaces This means is provided in a regular system c channels called blood-vessels, which run from the digestiv tract to all parts of the body. In the anterior portion of the tract the food undergoes digestion, and it is only ready for the use of the tissues when it reaches the intestine, so there is over this region a special plexus or tangle of minute blood-vessels called capillaries. The walls of the capillaries are only one cell thick, therefore the nutriment can easily pass into them through the lining of the intestine, and once in the vascular system it can be transported all ove the body. The purpose of the typhlosole can now b understood. In order that absorption may go on rapidly

it is necessary to have a large surface of the intestine in contact with the products of digestion. The cylindrical form of the worm's body does not allow of the tract's being folded or coiled, but the typhlosole takes up no space in the body-cavity and gives just the extra surface that is required for the tangles of the tiny capillaries. The valuable part of the food is taken away by these vessels, while what is worthless travels on and is at last thrown out of the body as the castings.

The whole vascular system is very complex, and the vessels are continuous, so that blood will come back again to the place from which it started, or will circulate. Certain of the vessels are contractile and serve as force-pumps to send the blood on. The large dorsal vessel has already been referred to (p 94). This is contractile and sends the blood forward in the body, and also into five pairs of pulsatile 'hearts' (Fig. 37, *h*) situated on either side of the digestive tract in segments vii to xi. Beneath the alimentary canal they discharge into a median ventral vessel, which carries the blood backwards again. There are special systems of vessels for the nerve-cord, for the excretory organs, and for the skin, as well as for the digestive tract (see above), and always the large trunks give place to smaller and smaller branches until the tangles of capillaries are formed to give the connecting link and complete the circulation.

Special organs of respiration do not occur; the soft damp nature of the body-wall and its plentiful vascular supply render the intake of oxygen and the output of carbon dioxide by diffusion a perfectly simple matter. The blood itself is a thin liquid of a reddish colour, containing numerous colourless amoeboid corpuscles. The colour is due to the solution in the liquid (or plasma) of a pigment containing iron and known as haemoglobin. This pigment has the power of entering into an unstable chemical relation with oxygen, and as readily parting from it: thus oxygen can be conveyed to the tissues. The corpuscles are quite similar to those of the coelomic fluid, and act as scavengers to the blood, by getting rid of any foreign bodies which may effect an entrance.

The excretory organs remove nitrogenous waste from the blood, into which it has been passed by the various

tissues of the body (cf. contractile vacuole of Amoeba). They are coiled tubes, called nephridia (Fig. 38), opening at one end by a funnel into the coelom, and at the other by a pore to the exterior (p 93). They are arranged segmentally, a pair to each segment excepting the first three and the last. They are assisted in their work by certain yellow cells which form an outer investment to the intestine. When these cells are full of waste material they fall into the coelom, and are then devoured by the amoeboid cells of the coelomic fluid which make their way to a nephridium and pass their contents through its wall. The sum of the

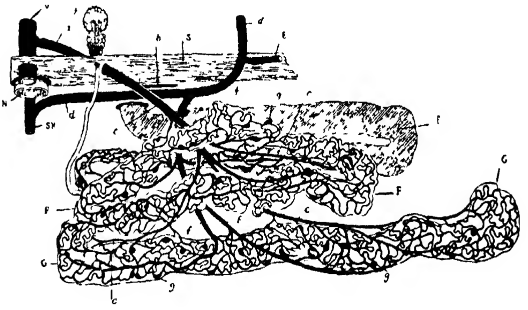


FIG 38 Nephridium (From Beddard, after Benham)
a, b, c d, e, f blood-vessels g dilation of capillaries E, F, G. loops of nephridium N nerve-cord S. septum SN. subneural vessel V ventral vessel

waste material in the nephridium is ejected by the contraction of the terminal part of the tube, which opens, as has been noted, between the two pairs of chaetae on one side or the other The nephridial funnel is ciliate. the cilia cause a rush of coelomic fluid into the organ, and thus accelerate the removal of the waste liquids

Each of the systems of organs which have just been described is complete in itself for the performance of a particular function, and yet each is dependent for its proper working upon all the others. The alimentary canal digests food for the whole body and all the tissues. the

nephridia and skin eliminate waste matters; the blood vascular system distributes nutriment from the alimentary canal and oxygen from the skin to every tissue, and at the same time carries waste products, carbon dioxide, water, and nitrogenous waste to the skin and the nephridia respectively. The blood-vessels, therefore, permeate every part of the body, and if all other tissues and organs could be removed, we should yet have a model of the earthworm in its blood-vessels, ranging from the hair-like capillaries to the great trunks. The nervous system, which must now be considered, is like the blood system in this respect of spreading throughout the body; and just as we may imagine a model of a worm in the red threads of its blood-vessels, so we may imagine another model in the white nerve-threads; but while the importance of the vascular system lies in its work of transport, that of the nervous system is its power of control over the working of every other organ, the blood-vessels included. The nervous system receives impressions from the outside world and co-ordinates movements with these impressions; it also receives impressions from all parts of the body itself, co-ordinating movements with these, whether they are the result of a normal healthy working, or of the irritation caused by foreign matters or disease. The nervous system consists of two chief parts: the peripheral system, comprising the nerves, whether sensory (receiving impressions) or motor (controlling movement), which ramify into every tissue of the body; and the central system, consisting of the nerve-chain which lies medianly on the ventral aspect of the coelom.

Lying upon the pharynx in segment III, and very clearly seen in a worm opened under spirit, is a pair of small roundish white bodies; these are the supra-oesophageal or cerebral ganglia. A white thread or connective arises from each of them to pass on either side of the pharynx and so to form a nerve collar, which is completed by a pair of ventral swellings, the sub-oesophageal ganglia. From these ganglia a double cord, whose halves are, however, only indistinctly visible, traverses the whole length of the body on the ventral side, swelling out slightly in each segment, to form again paired ganglia, from which three nerves are given off on either side; the body generally is supplied by these nerves. The cerebral ganglia give

off a large pair of nerves to supply the prostomium, which seems to be specially sensitive. The ganglia are aggregations of nerve cells, large cells, much branched, and with marked nuclei

In the earthworm there is relatively slight response to external stimuli it will withdraw rapidly from such a source of light as a candle, but it seems to be the heat given out rather than the light, which is appreciated. Again, a worm is sensitive to sound vibrations, and will recoil from a heavy tread upon the ground near, as well as from a louder noise. The animal exhibits some powers of taste, or more probably smell, for it seems to prefer certain foods to others, for instance, it will select scraps of onion from other vegetable matters The sense organs themselves are simply groups of cells scattered among the ordinary epidermal cells and frequently projecting beyond the surfaces as delicate sensory hairs these cells are probably sensitive to touch, warmth, and vibrations indiscriminately. Upon the prostomium, however, the organs are somewhat more specialized They are knots of cells set upon the terminations of the dorsal nerves to which reference has been made above To these organs is probably due the ultra-sensitiveness of the prostomium as a tactile organ.

Reproduction is effected in Lumbricus by the fusion of gametes, called, as in Hydra, ova and spermatozoa. Ovaries and testes are found in the same individual. The ovaries (Fig 39, *C*) are two somewhat conical bodies hanging from the anterior septum of segment XIII ventrally, one on either side of the nerve-cord Upon the posterior septum of this segment, immediately below each ovary, lies a funnel, whose narrow neck pierces the septum so that the oviducal aperture is in segment XIV. Close to the septum the oviduct is pouched to form a sac for the storage of eggs until they are laid. There are two pairs of digitiform testes (*T*) attached to the anterior septa of segments X and XI, one pair to each Like the oviducts, each spermiduct or vas efferens opens below its testis by a large funnel, the ducts of either side uniting to form a discharging tube or vas deferens which opens to the exterior in segment XV The reproductive organs are enclosed in special pouches of the coelom known as sperm-sacs. These vary in size with the season of the year,

being largest in the spring and then completely covering in the ventral space between septa x to xii They are provided with lateral offsets to the number of three pairs, and these may be of such a size as to bend back and cover over the digestive tract. The spermatozoa are not fully formed

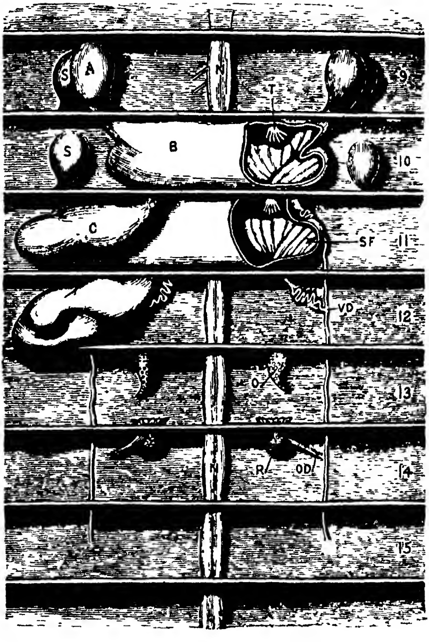


FIG 39 Diagram of reproductive organs (From Marshall and Hurst.)

A	anterior lateral sperm-sac	R	egg-sac
B	anterior median sperm-sac.	S	spermatheca
C	posterior lateral sperm-sac	*S*	funnel of vas deferens
N	nerve-cord	T	Testis
O.	ovary	VD	vas deferens.
OD.	oviduct	9–15.	segments ix to xv.

in the testes the cells composing these organs become plate-like bodies containing numerous nuclei, each of which represents a future spermatozoon. The multinucleate bodies drop from the testes into the vesiculae and there assume, after complicated changes, the characteristic 'tadpole' shape of the spermatozoon Then they find their way to the funnels of the vasa efferentia, and so to the exterior It is at this time that the spermathecae come into use Although ova and spermatozoa are formed by the same worm, they do not conjugate, but spermatozoa from one worm are necessary for the development of ova from another. The spermatozoa from the other worm are stored in the spermathecae until the ova are ready to be laid, and then about four of the latter, with a sufficient number of spermatozoa, are enclosed in a cocoon of mucus secreted by the cells of the clitellum, and fertilization takes place here Usually only one little worm develops in each cocoon

There is no production of new individuals by budding in Lumbricus it is true that if a worm be cut in two each half will complete itself by the formation of either a head or a tail end, but this must be regarded as an accidental and not as a usual occurrence, though it shows the power of regeneration or of replacing lost parts A fresh-water Chaetopod, Lumbriculus, nearly allied to Lumbricus, has a habit of breaking up into pieces, each of which may regenerate both head and tail, thus increasing its numbers; in others (Nais, &c), there is a regular formation of new individuals by budding A budding zone arises at the posterior end of the body, immediately in front of the last segment New segments are produced rapidly from this zone, to the number of five or six, then a constriction appears, marking off the new segments from the parent form, and the front one takes on the character of a head. This process may be repeated until there results a chain of worms which may hold together for some little time In other forms the budding worm bears no reproductive organs, these are found only in worms arising from the buds, an arrangement recalling the condition of things in Obelia, and called 'alternation of generations'. A rhythm of a rather different kind, consisting in the alternation of gamete-bearing and spore-

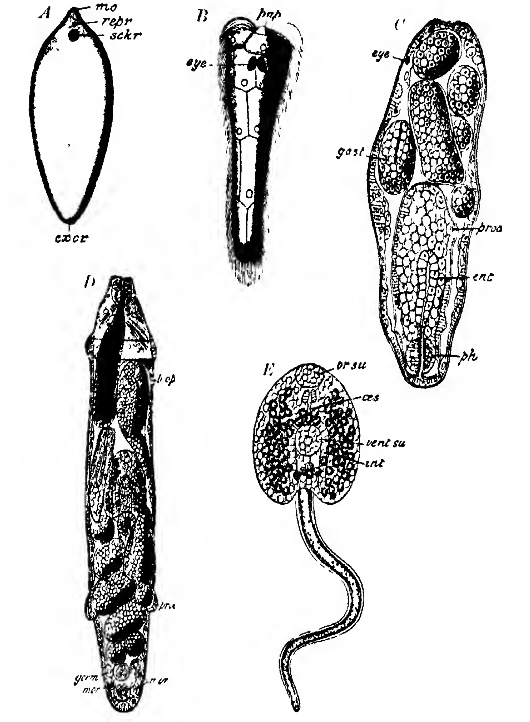


FIG. 40. *Distomum hepaticum* (From Parker and Haswell.)

A adult, natural size
B ciliated larva
C sporocyst, containing rediae in various stages of development.
D. redia, containing a daughter-redia and cercariae
E. fully developed cercaria
excr excretory pore
gast, *germ*, and *mor* developing embryos
int intestine
mo mouth
pap anterior papilla
ph pharynx
proc process of redia
repr and *b. op* reproductive pore
sckr and *vent su*. posterior sucker

bearing forms, is common in plants (see p. 196), rare in animals, but it does occur in the life-history of a few insects, and of certain parasites which are probably related, though not very nearly, to Lumbricus. These life-histories are of so great interest, and the adaptations of the organisms to their surroundings are so complete, that a sketch of one may well find a place here

The liver-fluke, *Distomum hepaticum* (Fig. 40), is found in the bile-ducts of the sheep. It is of a flattened oval shape, with a conical projection at the anterior end bearing an attachment-sucker at the tip a second sucker is situated on the ventral surface, about a third of the length of the body backwards The digestive tract consists of pharynx, oesophagus, and a long forked intestine, one limb running on either side of the body and bearing numerous offsets or diverticula There is a well-developed excretory system, small tubules open at last into two long lateral tubes, and these discharge to the exterior at the posterior end of the body in a common pore There is a supra-oesphageal ganglion, whence two stout nerve-cords pass backwards on the ventral aspect. Ovaries and testes occur both in the same individual, and present great complexity of structure and arrangement The eggs, encased in horny shells, are laid within the bile ducts of the sheep and pass out of its body to begin their development in a free state A larva is hatched which swims about in water by the aid of a thick coat of cilia, and in addition to means of locomotion it has a sense organ or eye-spot, both adaptations to a free-living existence. Unless within a few hours it meet with a special water-snail, the larva dies, but if this snail (*Limnaea truncatula*) be forthcoming, the larva bores its way, by means of its anterior papilla, into one of the organs and there loses its cilia, becoming a sac-like body called a sporocyst. Within the sporocyst germ-cells arise and develop, without conjugation and still in the parent body, into other sac-like bodies or rediae The redia again produces germ-cells, which without conjugation give rise either to other rediae or to little oval, tailed organisms known as cercariae. When a cercaria has escaped from the parent body, it works its way out of the snail, and swims freely for a time, by means of its muscular tail. Then it creeps on to a water-

weed or blade of grass, loses its tail, and forms for itself a cyst from the contents of certain glands in its body. If the plant bearing the cercaria be eaten by a sheep, the cyst dissolves, and the fluke, which has been maturing during the resting period, escapes and finds its way to the bile ducts of its host. The life-history may be expressed in a table where = signifies a metamorphosis, or occurrence of the same individual in a new form, and | indicates a new generation

Egg = larva = sporocyst
|
redia
|
cercaria = fluke

There is here a real alternation of individuals giving rise to gametes, with others which produce what may be called spores, inasmuch as they are cells capable of developing into new individuals without conjugation. That there are two spore-bearing generations to one gamete-bearing generation does not affect the alternation, which is perfectly regular, but evidently quite different from that to be seen in the budding worms referred to above, while it is in accordance with the alternation which is so marked in the higher plants (p. 196)

With one exception (Syllis) lateral budding is unknown among the Chaetopods wherever else this mode of reproduction occurs, it results always in the formation of a linear chain of buds which breaks up later The new segments which form the buds arise, like those which will increase the length of a non-budding worm, from a region immediately in front of the terminal segment, and it was this circumstance which suggested the possibility of explaining the segmentation of the non-colonial forms by supposing that the new segments are formed as buds which become incorporated in the body and only add to its length. It is more likely, however, that the formation of buds is an adaptation of the segmentation process. In Lumbricus, for instance, the divisions of the coelom arise in linear series ; the nephridia and the nerve-ganglia are formed in the same manner, the oldest being always the farthest forward it is highly probable that the linear

repetition was shown first by the internal structures, notably by the coelom, and that the grooving of the body-wall to form complete segments or metameres fell into relation with this In an elongate animal, pieces of the end of the body are likely to be injured or lost, and it is obviously of advantage to have the organs repeated, so that death may not follow damage When once metamerism is established in respect of the internal structures, a corresponding pouching of the body-wall is likely to ensue It is also useful to an animal which moves by 'wriggling' to have a very flexible body, and segmentation makes for flexibility If the origin of metamerism may be accounted for in this way, the production of buds may be regarded as a step further in the same process. To what an extreme budding may be carried may be seen by an investigation of the life-history of a relative of Distomum, again a parasite, Taenia, the tape-worm It may be well to digress here for a moment to explain the use of the term 'worm' All animals without backbones, with long, soft bodies, and with a creeping habit, were formerly known as 'worms', and were put together by Linnaeus to constitute a group, Vermes Later investigations, however, have shown that they have little close relationship with one another, and just as Botanists are finding it necessary to abandon the plant group Algae (p 53), so Zoologists have been obliged to break up the Vermes. Yet the name 'worm' is still applied in a general sense to many animals with very different characters for instance, Distomum is often called a flat-worm, Taenia is known as the tape-worm, Ascaris, which will be considered presently, the thread-worm, and so on

Taenia (Fig 41) is parasitic in many of the higher animals The adult worm may attain a great length, up to twenty yards, and consist of a head or scolex, and an enormous number of segments called proglottides Unlike the Chaetopods, Taenia has its budding zone immediately behind the head, so that the oldest segments are the most posterior The head is somewhat club-shaped, and may bear hooks and suckers for attachment to the alimentary canal of the host it is followed by the neck, a narrow region passing into the budding zone. The segments are all alike except that they increase in size as they get

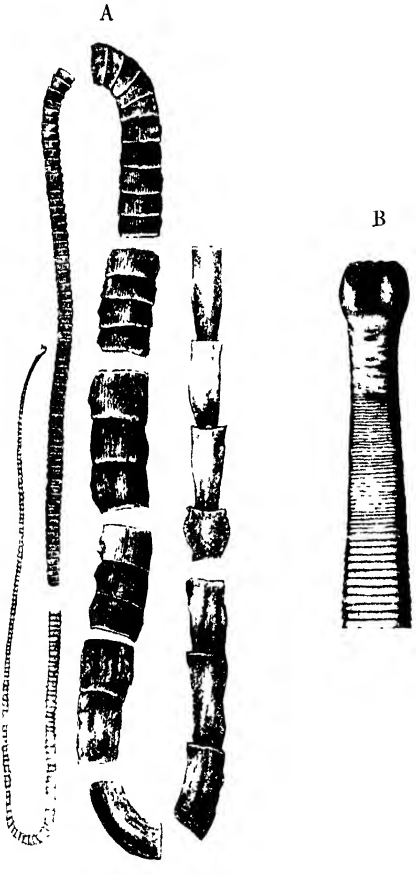


FIG 41 A. *Taenia saginata* B Young *T serrata*, showing head with hooks and suckers (From Leuckart)

older and farther from the head. Ovaries and testes are borne by the same individual, and there is a complete set of reproductive organs in each proglottis, their general arrangement showing a great similarity to that of Distomum, and thus indicating the kinship of the two organisms There is no trace of a digestive tract, and the only external apertures are the reproductive pores on each segment. The nervous and excretory systems are on essentially the same plan as those of the fluke, and are continuous from the scolex throughout the whole length of the proglottides The eggs, which may be fertilized by spermatozoa from the same segment, develop in another host, usually in some animal upon which the final host

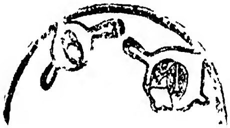


FIG 42 Diagram of the production of new individuals by budding from the walls of a proscolex (From Leuckart)

preys For instance, in *T serrata* (Fig 41, B), which begins life in the rabbit and becomes mature in the dog, the eggs are picked up by the rabbit, in whose digestive tract they hatch out as rounded embryos, each bearing six hooks. With the aid of these hooks, they work their way into the muscles of the viscera where they develop into cysts known as proscolices At this stage a transference to the dog must take place, which results from that animal's eating the rabbit and thus receiving the parasite into its alimentary canal The walls of the proscolices give rise on the inner sides, by a process of budding, to one or several scolices according to the species. Each scolex is thrust out from the vesicle much in the way that the thread is shot out from a nettle cell of Hydra the budding zone is soon established, and a rapid formation of proglottides takes place.

In Taenia the retrogressive development due to the parasitic habit has gone to greater lengths than in Distomum;

in both there is an absence of sensory and locomotor organs, a softness and flexibility of body, and the presence of hooks or suckers for adhering to the tissues of the host, with great elaboration of the reproductive organs. In addition to all this, Taenia exhibits the great peculiarity of the entire absence of digestive tract, a circumstance of very great rarity. In both animals there is a complicated life-history, depending upon the occurrence, at appropriate moments in each case, of two distinct hosts in Taenia a further complexity arises owing to the formation of numerous segments, which may break away from the parent and pass out of the host independently Each of the segments contains great numbers of eggs, and by becoming separate from its fellows gives still greater facilities for the infection of new hosts, and hence for the dispersal of the species.

FIG. 43 *Ascaris lumbricoides*

In Ascaris (Fig. 43), which is also a parasite, there is a nearer approximation to the structure of a free-living form, the parasitic habit has but a slight effect upon either the structure or the life-history of the worm. *Ascaris lumbricoides* inhabits the higher animals. Its body is elongate, firm, and stiff, rounded in section, and greyish- or whitish-brown in colour four paler lines run the whole length of the body from tip to tip. The anterior end bears three marked lobes surrounding the mouth and bearing sensory papillae. There are no organs of locomotion. There is a well-developed digestive tract, and nervous and excretory systems are in no way degenerate. Testes and ovaries are found in distinct animals, which may be readily distinguished from one another. The eggs, which are laid in great numbers, pass out of the body of the host independently of their parent, and prob-

ably reach a fresh host in drinking-water or in vegetable food. The embryo develops within the egg-shell, and while thus protected is killed by neither summer heat nor winter frost; it may, indeed, survive all such changes for years, and then, safe within a suitable host, escape from the egg and attain adult life. Only one host seems to be necessary for the development of this worm.

CHAPTER XIV

THE CRAYFISH (*Astacus Fluviatilis*) AND ITS ALLIES

The crayfish is a fresh-water form, inhabiting holes in the banks of streams and rivers It is now far from common in England, and is becoming scarce in Western Europe, though it still flourishes farther east It is esteemed as an article of food in the same way as are the larger prawns, and in some parts of France and Germany it is cultivated The body shows far greater complication and specialization than that of the earthworm, and whereas the latter is eminently a terrestrial animal, the crayfish is very perfectly adapted to an aquatic life To the first glance, the most noticeable point in the body is its hard covering or exoskeleton, a closer inspection discovers that, like the earthworm, it is segmented, but the segments are diverse and are grouped into regions these are generally known as head, thorax, and abdomen. The animal exhibits bilateral symmetry and each of the segments is provided with a pair of appendages, which are appropriated to various functions, sensory, nutritive or locomotor The exoskeleton consists of series of plates which are formed by the deposition of lime-salts in definite parts of the chitinous cuticle (cf Lumbricus, p 94), and they can move upon one another, for the cuticle between them is left uncalcified and so gives flexible joints In the head and thoracic regions there is a great fusion of segments, but in the abdomen they are all free, and here the hard plates are seen to be a dorsal tergum which is curved and prolonged at either side into a flap called a pleuron, a ventral sternum, and laterally at each side between tergum and sternum, 'facing' as it were the pleuron, a small plate called an epimeron. The appendages are attached to the sides of the sterna, and are covered by exoskeletal plates, which are here, however, in the form of hollow rings, but still united by the uncalcified skin, so that,

like the body, the limbs are jointed Certain of the appendages are adapted as walking-legs, and the crayfish can use them in moving upon the bottom of the stream, it can also swim, or at least shoot through the water by

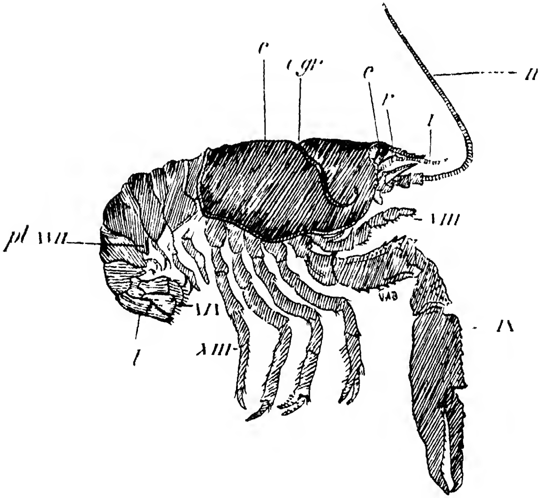


FIG 44. *Astacus fluviatilis*

c	carapace	i	antennule
c gr	cervical groove	ii	antenna
e	eye.	viii	third maxilliped
pl xvii.	pleuron of seventeenth segment	ix	chela
r	rostrum	xiii	last thoracic leg.
t	telson	xix.	appendage of sixth abdominal segment

the action of the strongly-jointed abdomen, which can be bent against the rest of the body and then extended with a jerk, so as to thrust the animal backwards for a considerable distance. Such methods of locomotion can clearly be available only in water, and in its breathing apparatus

Astacus is just as completely adapted to an aquatic life. The hard exoskeleton does away with any possibility of an exchange of gases through the skin such as goes on in the earthworm, so we find gills, delicate foldings of the soft part of the body-wall, projecting into the water within them, blood capillaries are numerous, and thus a ready exchange of gases can go on by diffusion to and from the water Gills of this kind would be a real danger to a land animal, as they would dry up at once out of water Of the apertures upon the surface of the body, the mouth is ventral and lies near the posterior limit of the head, the anus is also ventral, but far back upon the last abdominal segment, the openings of the gonads are upon a pair of the thoracic limbs, and those of the excretory organs upon the second pair of head appendages.

Crayfish are omnivorous feeders, and, like the earthworm, will attack their brethren, and not only dead ones. In winter, when food, whether vegetable or animal, is scarce, the crayfish keeps in its hole, coming out again with the warmer weather It sheds its cuticle, or moults, periodically The newly-moulted individual is clothed only with a soft skin, and while this is hardening remains in hiding This animal has considerable power of replacing lost limbs parts may be shed during a moult, but voluntary mutilations are by no means rare, if caught by one of the great claws, for instance, the owner is apt to throw off that part and to escape without it Although an ordinary wound bleeds freely, no loss occurs from such a mutilation the crayfish sheds the claw from a particular joint, and the muscles contract to prevent any flow of blood A covering, probably of coagulated blood, is formed over the wound, and later upon this surface appears a bud, which gradually assumes the size and shape of the lost claw The general colour of the animal is a greenish-grey this is due to the presence in the skeleton of a pigment which turns bright red on boiling, or a duller red on immersion in alcohol.

In connexion with the specialization of parts of the body, there are fewer segments in the crayfish, which has only twenty, than in the earthworm, where there are 150. Of these twenty segments, five form the head, eight the thorax, and seven the abdomen. The head segments

are fused firmly together, but can be counted by the number of pairs of appendages The thorax also forms one mass, and is fused with the head to constitute what really comes to be one region, the cephalothorax. Dorsally this is covered over by a continuous shell or carapace which forms the body-wall upon the back, but is prolonged on either side as a flap, standing away from the true body-wall so as to enclose a lateral chamber in which the gills are contained The limits of head and thorax are indicated by a groove, the cervical groove, which runs somewhat crescentically upon the carapace, its convexity pointing backwards In front of the head, the carapace ends in a sharp-toothed process, the rostrum, behind which it is curved on either side to form a hollow in which lies a stalked eye The several segments of the head are distinguishable alike on dorsal and ventral aspects, but the sterna of the thorax are distinct, though only the last one is movable The seven abdominal segments are all free, the terga are curved, and the pleura are well-developed except upon the first segment, from which they are absent, the sterna are little more than transverse bars, much narrower than those of the thorax, and separated by relatively wide expanses of membrane which allows of the flexion of the abdomen for swimming The terminal segment, sometimes known as the telson, is unlike the others, for it is long, narrow, flattened, and destitute of pleura it is transversely jointed at about the middle of its length. The great flexible abdomen of the crayfish and its powerful thoracic limbs, necessitate strong muscles to effect movements. The simple muscle-tunic of the earthworm would be of no use here instead, there are great bundles of muscle each attached by one end to one skeletal piece and by the other to some other hard plate, so that, when it contracts, a pull is put upon the limb or part of the trunk to which it belongs and a definite bending of the joint results. In addition to the outer hard parts, there is, inside the thorax on its ventral aspect, another skeletal arrangement (Fig. 47, *end.*), the endophragmal skeleton, which is really composed of complicated inpushings of the exoskeleton. This gives further attachment for the muscles of the legs, and to those for the flexion of the abdomen, it also comes to enclose

a narrow sternal canal within which lie the nerve-cord and the ventral blood-vessel

The structure of each limb is modified in connexion with the function which it performs, but all may be reduced to a common type consisting of a basal part or protopodite bearing two much-jointed branches, the endopodite and exopodite Of the five pairs belonging to the head, the first and second are of the nature of sensory organs, the other three pairs have to do with the prehension of food. The first pair, or antennules, conform to the common type the protopodite is three-jointed, the exopodite and endopodite are both much divided, and they are fringed with delicate hair-like structures or setae, which are very characteristic of the crayfish and its allies (Fig 45) Some of these setae have probably an olfactory function. The so-called auditory organ is lodged in the basal joint, which is perforated by the 'auditory' pore The antennae (Fig 45, ii), the second appendages, have each a two-jointed protopodite, an endopodite of great length and many segments, and an exopodite which forms a stout, sharp-pointed, up-standing blade The antennae are the long 'feelers', which are so marked a feature of Astacus, and probably serve as tactile organs In connexion with the prehension of food, there are, besides the mandibles and two pairs of maxillae which belong to the head, other three pairs which are really thoracic limbs pressed into the service of the mouth and known as foot-jaws or maxillipeds, all these pairs of appendages lie one over the other and quite conceal the mouth The outermost, which are really the hindmost, are the third maxillipeds (viii), and, as they approach most nearly to the common type, will be described first, points wherein the others differ from them being mentioned later In the third maxillipeds, then, the protopodite is compact, the exopodite small, and like the stouter endopodite, jointed Yet another part, the epipodite, is found upon these limbs it is a broad flat plate attached to the protopodite and bearing a gill. The second foot-jaws are like these, and in both is indicated what we shall see presently, the strengthening of the endopodite and the dwindling of the exopodite In the first maxilliped, this condition of things is reversed, the endopodite is smaller than the exopodite In the second

maxillae, again, the endopodite is slender and pointed, while the exopodite (v) forms an elongate flattened process which takes on a special function in connexion with respiration, and will be referred to again. The protopodite forms four leaf-like expansions, and this flat character is shared by the first maxillae (iv) which are small and delicate The mandibles are very different from all the other limbs (iii) they have each a stout, transversely elongated protopodite, the inner edge of which forms a biting and crushing surface, provided with toothed ridges Here again it is the exopodite which is wanting, and the endopodite, though present, is merely a short, jointed process Turning back to the limbs behind the third maxillipeds, we find in the rest of the thoracic legs a complete disappearance of the dwindling exopodite. In all five pairs, viz., the great claws or chelae and the four pairs of walking legs, the protopodite is divided into two parts, and the large endopodite is seven-jointed. In the chelae and the first two pairs of walking legs the last joint but one is produced, and with the terminal piece forms the strong and characteristic pincers (xiii) The walking-legs are slender and contrast with the exceedingly bulky chelae, and all but the last, as well as the chelae, bear gills: upon the basal joint of either the second or the last pair is the orifice of the duct of the reproductive organ. The abdominal appendages show a return to the common type of limb. It is true that in the female crayfish the first pair is wanting, and in the male it is modified in connexion with its service in the reproductive function (xiv, xv), as may be the second also, but the general plan is always the simple one of protopodite with well-developed and jointed endopodite and exopodite The sixth are large and spreading (xix), both exopodite and endopodite are flattened and expanded (the latter shows a transverse division), and with the telson constitute a very efficient tail-fin, which bears its part in carrying its owner through the water. The other abdominal appendages move all together with a rhythmical swing, and probably assist in progression when the animal is walking

The limbs have been described in some detail, because their number, with their diverse forms and functions, is a striking feature of the crayfish, and also because they

give an interesting illustration of the way in which some one kind of organ may be adapted in many directions for special purposes. Adapted for locomotion are the walking legs and the abdominal limbs (swimmerets); for grasping, the chelae; in the service of nutrition, the mandibles, maxillae, and maxillipeds; in connexion with reproduction, the first abdominal appendages, and as sensory organs, the antennae and antennules[1] Six sets may, therefore, be recognized, with a great diversity of form, but always an underlying unity of structure. It is easy, indeed, to imagine that the ancestor of the crayfish had a body consisting of a head and a limited number of similar segments, each bearing a pair of similar unmodified limbs built very much on the plan preserved in the abdominal appendages of its descendant As in successive generations the crayfish type began to be more clearly marked out, specialization in various directions, and notably in the legs, was initiated, and continued until all the different forms of limb displayed by the modern crayfish were evolved It must be borne in mind that a supposition such as this is merely a supposition, though we may refer to fossil forms as well as to modern relatives of the crayfish in its support; at the same time, it is essential to remember that unless some evolution such as that suggested above have taken place, the underlying similarity in this series of appendages is absolutely meaningless

The adaptation of the animal to aquatic conditions is seen chiefly in the arrangements for respiration, and these may well be described here, as the gills are so closely connected with the thoracic limbs The floor of the gill chamber is formed by their basal joints, while its inner wall is given by the fused epimera of the thoracic segments of either side, the outer wall and roof by its pleura (the flaps of the carapace) The gills, twenty in number on either side, are borne by the body-wall, by the bases of the

[1] It should, perhaps, be mentioned that some authorities regard the stalked eyes as true appendages and as representing an extra head-segment the eye-stalks are short and stout, composed each of two joints, freely movable, and capable of being withdrawn into their sockets at the sides of the rostrum It seems probable, however, that they are merely special developments to bear the eyes, and belong to the prostomial region (cf earthworm), which is always sensitive and never, in any allied form, bears limbs

legs, and by the membranes which attach the legs to the body. It has been noticed that in those attached to the legs, the delicate foldings of skin are supported by the epipodites. These gills have, therefore, a somewhat flattened appearance. Those attached to the body-wall or joints have a median support round which the folds are arranged so that the whole looks rather like a bottle-brush. The movements of the limbs, of which the basal joints form the floor of the gill-chamber, cause a certain interchange of water between the chamber and the exterior this is chiefly effected, however, by the baling action of the exopodite of the second maxilla (Fig 45, v, *exp*), which works in the anterior narrow part of the chamber, and as stale water containing carbon dioxide is scooped out in front, clean water rushes in from behind, and so the gills are kept supplied with oxygen The oxygen passes into the capillaries of the gills, and so reaches the blood vascular system for distribution to all the tissues.

In the vascular system of the crayfish the segmental arrangement obtaining in the earthworm is completely obliterated, and it is difficult to see any similarity between the two systems Perhaps the dorsal vessel of the worm may be represented by the heart, and the median vessels running backwards and forwards from it, and again, a vessel lies beneath the nerve-cord in both animals; but the relations of the parts are generally very different. Blood is pumped all over the body in Astacus by one heart, not by several pairs of pulsatile vessels This heart is a pentagonal muscular sac (Figs 46, 47, *h.*) lying in a blood space called the pericardium, which occupies the dorsal part of the thorax It is pierced by three pairs of holes, all guarded by valves, which allow of an ingress of blood from the pericardium, but prevent its escape back again. Blood leaves the heart by well-defined vessels called arteries, which branch off in all directions, and it may be noted here that vessels carrying blood from a heart are always called arteries, while those which return it to a heart are known as veins In the crayfish, the veins, unlike the arteries, are merely irregular spaces or sinuses, of which the most important is the pericardium, but before reaching that, the blood from the arteries passes to a large ventral sinus, whence it is conveyed by narrower vessels to the

gills to be oxygenated. This blood, which is carried from the gills straight to the pericardium, rushes into it as the heart contracts, and is drawn into that organ itself when

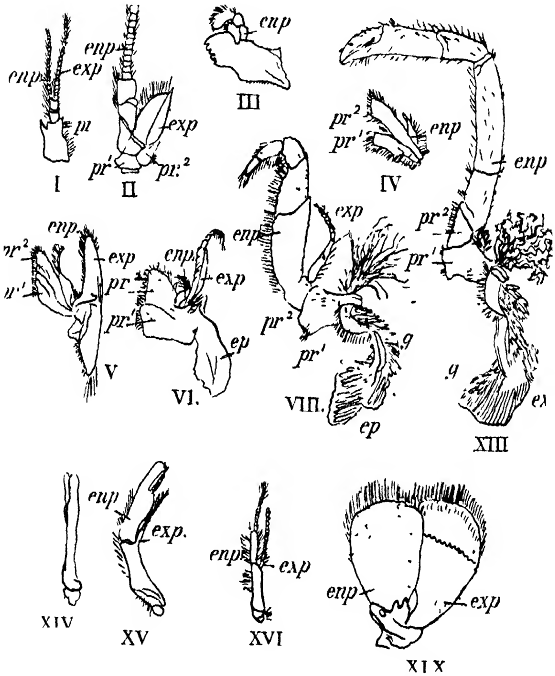


FIG 45 Appendages (After Parker and Haswell)

enp endopodite — *g* gill
ep. epipodite — *pr.* protopodite.
exp exopodite.

it dilates again, through the paired apertures thus the heart contains only arterial blood. When exposed to air the blood is of a deep blue tone, due to the presence of

a pigment containing copper and called haemocyanin when deprived of oxygen it loses this colour. As in the earthworm, it contains colourless amoeboid corpuscles.

Besides oxygen, the blood carries, of course, food for the tissues, and consists, in part, of digested foodstuffs. The region of the alimentary canal from which the nutriment is removed is very short, for by far the greater part

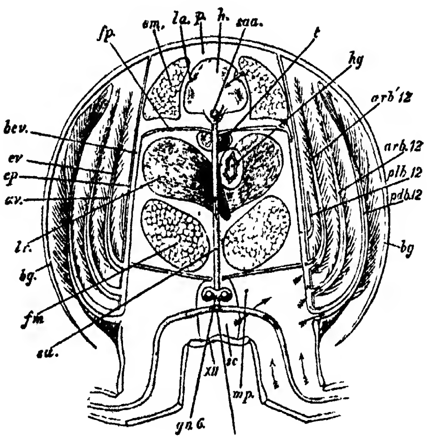


FIG 46 Diagrammatic transverse section of thorax through segment xii, showing the course of the circulation of the blood (From Huxley)

arb 12, *arb′* 12, *pdb* 12, and *plb* 12, gills belonging to the segment
av and *ev* afferent and efferent branchial vessels
bcv sinus from gills to pericardium
bg lateral flap of carapace
em and *fm* muscles of abdomen
ep epimeral wall of thorax
fp floor of pericardium
gn 6 fifth thoracic ganglion.
h heart
hg. hind-gut
iaa ventral artery
la lateral apertures of heart
lr gastric gland
p pericardial sinus
sa sternal artery
saa dorsal artery.
t testis
xii sternum of twelfth somite

The arrows indicate the direction of the blood-flow.

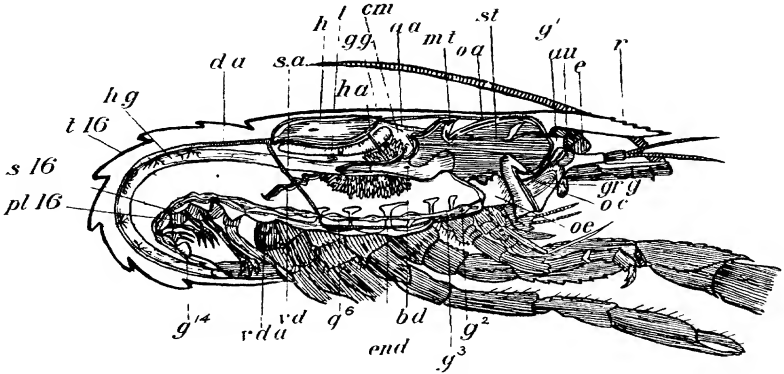


FIG 47 General dissection of a crayfish from the right side (After Marshall and Hurst)

a a	antennary artery	*gr g*	green gland	*r*	rostrum
au	'auditory' organ	*h.*	heart	s^{16}	sternum of 16th segment
b d	aperture of gastric gland	*h a*	hepatic artery	*s a*	sternal artery
cm	caecum	*h g.*	hind-gut	*st*	stomach
d a	dorsal artery	*m t*	median tooth	*t*	testis.
e	eye	*o a*	ophthalmic artery.	t^{16}	tergum of 16th segment
end	endophragmal skeleton	*o c*	connective	*v d*	vas deferens
g^1–g^{14}	ganglia.	*oe*	oesophagus	*v d a*	aperture of vas deferens
g.g.	gastric gland	pl^{16}	pleuron of 16th segment		

of the tube has a chitinous lining, which is in fact a continuation or tucking-in of the external cuticle, and does not, therefore, allow liquids to pass through it. The canal has a single bend, almost a right angle, in the anterior part of its course, where the stomach forms the bend—one limb being the oesophagus, which passes vertically downwards to the mouth, the other the intestine, which runs horizontally back to the anus The mouth is a longitudinal slit, with parallel sides the jaws are external to it and when at rest conceal it completely (p. 115) Food is usually grasped by the large chelae, or by one of the

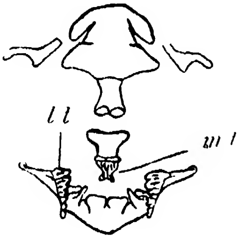


FIG 48 Plates of the gastric mill separated from one another (After Huxley)
l t lateral tooth *m t* median tooth

pairs of smaller chelate limbs, and is torn by them before being transferred to the third maxillipeds which, as well as the other jaws, tear it and crush it as they pass it on to the mouth. The mouth opens direct into the oesophagus (Fig 47, *oe*), a short wide tube running upwards into the stomach, which is a large chamber divided by a constriction into two smaller compartments (Fig. 47, *st*). In the anterior compartment the chitinous lining shows, dorsally, calcified thickenings or plates, which form the 'gastric mill', and may be seen on the outside of the stomach to be attached to the carapace by stout muscles The mechanism is a very complicated one, but it may be said, briefly, that the plates are arranged roughly in the form of two T's, with their uprights meeting, while lateral pieces

diverge from the ends of their distant horizontals (Fig 48). The hindermost T bears a stout ridged tooth upon each of its free ends, i.e one median where the two T's meet, and two lateral teeth. The parts are all freely movable upon one another, and the whole apparatus is provided with strong muscles, the main result of the action of which is the alternate bringing together and forcing apart of the teeth so that they crush and pound any food which may be present in the stomach. The walls of the posterior compartment are thrown into folds thickly fringed with setae, so that a very efficient strainer is formed, allowing only liquid or very finely divided solid food to pass on, while larger fragments are retained for further grinding, or, if useless, are rejected through the mouth Immediately behind the stomach is the mid-gut, the short region with soft walls (i e without the chitinous lining) from which absorption takes place It is produced dorsally into a pouch, possibly for further surface, and receives on either side the duct of a large digestive gland. These glands, which are prominent objects in the body-cavity on account of their size and their bright yellow colour (Fig 47, *g g*), are made up of numbers of blind tubules all opening at last into the mid-gut. They secrete a digestive liquid which acts upon the food prepared for it by the stomach In the hind-gut the chitinous lining is again seen (*h g*), and when the animal moults, the whole of this lining, together with that of the oesophagus and stomach, is thrown off At this time certain calcareous formations called gastroliths, which occur in the wall of the stomach, are at their largest, and then disappear Whether they are used up in forming the new skeleton, or whether they are waste substance from the old one, and therefore cast out with the lining of the canal, seems to be uncertain

In contrast to the series of nephridia of the earthworm, there is but one pair of excretory organs in Astacus, the green glands (*gr g*) lying far forward in the head at the base of the antennae Each organ consists of a coiled tube, part of which is glandular, having a small sac at one end, and opening by the other upon the protopodite of the antennae Excretion of certain substances is probably carried on by the gastric glands, but even if such be the case, there seems little provision for this function,

considering the size of the animal. Chitin contains much nitrogen, and it is, therefore, quite possible that nitrogenous waste is used in connexion with the formation of the exoskeleton, and got rid of when this is cast (cf. nitrogenous waste in plants, p. 26)

The nervous system (Fig 47 g^1-g^{14}), like that of Lumbricus, consists of a double ventral cord, but the parts here are more distinct There is a series of paired ganglia, the members of a pair are fused, and consecutive pairs are joined by double connectives There is really one pair of ganglia to each segment, but in relation with the modifications which have taken place in the fusion of head and thoracic segments, the separate ganglia have also become indistinguishable in particular, the sub-oesophageal mass probably represents five pairs From this mass two long connectives pass, one on either side of the oesophagus, to the dorsal or supra-oesophageal ganglion, which lies dorsally in the head (cf Lumbricus) Each of the segments from IX to XIX is supplied with nerves from distinct ganglia the alimentary canal is served by a special nerve formed by the union of a branch from the supra-oesophageal ganglion with two pairs given off by the connectives encircling the oesophagus

The nerves given off from the ventral series of ganglia regulate movements of limb and other muscles, but those from the supra-oesophageal would seem to be concerned not only with the movements of the antennae and eye-stalks, but also with the transmission of impressions from the organs of special sense The tactile function of antennae and antennules, and the position of the olfactory setae have been noted The so-called auditory organ is a transparent sac, continuous at its mouth, which is guarded by tufts of setae, with the exoskeleton of the antennule. Within, sensory setae arranged in rows project into the cavity, which contains grains of sand and other small foreign bodies. Vibrations are transmitted through the water to the setae, which are further influenced by the motion given to the solid particles in the sac, and probably stimulate the nerves which pass to them from the supra-oesophageal ganglion Like the cuticle of the digestive tract, the lining of this vesicle is shed during a moult, and the little grains of sand are lost, to be replaced by others picked up by the

animal itself. This sac is undoubtedly affected by vibrations in the water, but how far it may be considered an auditory, and how far a balancing, organ is not easy to determine it may be mentioned that in the higher animals the appreciation of sound and of position is always due to the activity of different parts of the same organ, the auditory sac (cf also the statocysts of Obelia, p 76) The eyes, which are borne upon special stalks, are compound, i e. each is made up of separate little bodies or eye-elements, capable of perceiving light. Each eye-element, the area of which may be seen upon the surface as a quadrangular facet, is composed of a transparent refractive part for concentrating the rays of light, and a perceptive part which is in connexion with a twig from the optic nerve Between the numerous eye-elements is much dark pigment. It is probable that the crayfish sees objects as mosaics, as made up of many tiny pieces fitted into one another Each eye-element must be able to see only such a tiny piece, for all rays of light, excepting those which pass directly to the perceptive part, are stopped by the packing of pigment.

In the crayfish, ovary and testis are not found in the same individual, as in the worm, and only one gonad is present in any one animal The ovary is a yellowish tri-lobed body lying medianly in the body-cavity behind the stomach and below the heart. Two of the lobes point forwards, and at their junction with the third a short wide oviduct is given off on either side to open to the exterior on the basal joint of the second walking limb of that side. The testis is similar in both position and shape (Fig. 47, *t.*) its ducts are long and coiled, narrower than the oviducts, and opening on the last pair of walking legs (*v d a.*) The spermatozoa are discoid, with curved chitinous processes projecting from the edge they are bound together by a secretion of the vasa deferentia into thick white threads, and these are deposited upon the female near the openings of the oviducts by the first and second abdominal limbs of the male, which are modified for the purpose (Fig. 45, xiv, xv) The eggs are laid in the autumn, and each is fertilized by one of the spermatozoa before passing on to the abdominal appendages of the female, to which it is attached by a sticky substance secreted by the

oviduct. The eggs do not hatch until the following spring, and even then the young ones still adhere to the abdominal appendages of the parent, holding tight by their great claws until after the first moult. Although certain changes in form take place with this moult the young crayfish when they hatch are essentially like their parents.

In the foregoing account of the crayfish, points wherein it may be compared or contrasted with the earthworm have been frequently indicated, but one very striking difference between the two animals remains for comment. The body-cavity of the earthworm is a well-defined series of compartments, entirely distinct from the blood vascular system, a great part of which, indeed, projects into it. In the crayfish, the space which surrounds the internal organs is a blood space, and the blood vascular system, so far from being compact and closed as it is in Lumbricus, forms in great part large and irregular sinuses. Again, the excretory organs in the earthworm open into the body-cavity in Astacus they terminate in small closed sacs Yet again, the gonads in Lumbricus are contained in the body-cavity and are themselves simply masses of reproductive cells which, when they break loose, just tumble into the cavity: in the crayfish they are closed sacs, in whose walls lie the gametes, and when these break loose they are conveyed straight to the exterior by ducts which are attached directly to the walls, and give no chance of escape into the body. It was noticed in passing that a body-cavity like that of Lumbricus (p 91) which contains the gonads, is known as a coelom, and it is upon this point that a little stress must now be laid. In the simplest of the higher animals, i.e of those after the grade of Hydra is passed, the reproductive organs always occur as pouches, communicating with the exterior. In more complex forms the pouch enlarges, so that its cavity becomes of considerable size, and the germ-cells occur in only a small part of its walls, or a whole pouch may be destitute of such cells. The pouches, now called coelomic pouches, may coalesce so as to form one large cavity, the coelom, which then serves as a body-cavity. In the earthworm, as we have seen, the pouched character is retained, the coelom

consisting of a series of compartments separated by membranous partitions; in the Vertebrates, to be studied presently, the pouches have coalesced. In Astacus the great development of blood space has resulted in the reduction of the coelomic pouches to their simplest form, as gonadial spaces, though the end sacs of the green glands may possibly be the last remnants of others.

The most striking character of the earthworm, its segmentation, is shown also by the crayfish, but here, as has been noted, there is reduction in the number of segments, and they are grouped into regions Other important features of the crayfish are its calcified exoskeleton and its jointed limbs, some of which form jaws. These characters are exhibited by many other animals, which are in consequence regarded as allies of Astacus and brigaded with it to form the great group Arthropoda. Within this group, smaller divisions have been made in accordance with important structural differences displayed by animals which yet present the chief arthropod points Astacus and its relatives, which are called crustaceans, are typically aquatic, most other Arthropods, as centipedes, spiders, insects, are typically terrestrial, and hence display many adaptations to fit them for a life on land. For instance, their legs, many in the centipedes, eight in the spiders, and six in the insects, are specialized for walking; and as these animals must breathe air, their respiratory organs consist of air-tubes or air-sacs contained within the body The Insecta are very strikingly adapted in this way, and, in addition to the three pairs of legs, even possess wings for locomotion in air. The gnat or mosquito (Fig. 49), one of the insects, will now be described it is of entirely terrestrial habit during adult life, but spends all its early stages in water, and presents, therefore, a very interesting life-history. it is also important in being a danger to higher animals as a carrier of disease (p 35).

The body of the gnat is divided into head, thorax, and abdomen. The head is rounded and bears two large compound eyes, which are sessile, and approach one another, but do not meet, in the middle line. In front of the eyes is a single pair of antennae; these are jointed and bear tufts of setae at the joints: in the male, the setae are curved,

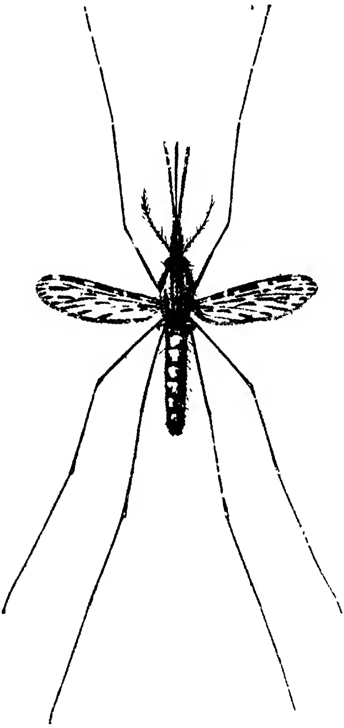


FIG 49 The malaria mosquito, Anopheles. (From Giles)

and so numerous as to obscure the axis, while in the female they are fewer in number and much smaller. Three pairs of jaws are present, mandibles and two pairs of maxillae, but they are modified to form, with an outgrowth of the lower lip, an apparatus for puncturing the integument

of some other animal, or the epidermis of a plant. The head is attached by a well-marked neck to the thorax, which consists of three segments, each bearing a pair of legs, but fused to form an undivided mass, the wings, a single pair only, are borne by the middle segment, the last segment bears on either side a small club-shaped appendage which is to be regarded as a balancing organ, and is a modification of the second wing The abdomen is made up of nine segments, of which the last bears a pair of lobed processes, which are concerned with the transference of the spermatozoa, or the deposition of the eggs. The anus lies ventrally on the eighth segment The stigmata, the paired openings of the respiratory tubes, are situated on either side of each thoracic and abdominal segment.

Before considering the life-history of the gnat, we must look for a moment at its digestive tract, and especially at the working of the mouth parts. The mouth leads into an oesophagus capable of dilation in its median portion, the oesophagus opens into a long wide stomach, this in its turn passes into the intestine which opens to the exterior Discharging into the oesophagus are two pairs of salivary glands and a pair of poison glands it is the secretion of the latter which causes irritation to the victim of a gnat-bite, but probably it benefits the gnat by preventing coagulation of the blood sucked in. A puncture is made by the piercing part of the mouth parts, and the median portion of the oesophagus dilates, causing a decrease of pressure in that region, and blood rushes up to fill the space. It is not easy to understand why the gnat sucks blood, apparently only the female has this bad habit, and since gnats are very numerous in places where no 'animals worth biting' occur, e g. some parts of the Arctic regions it can be necessary neither to their well-being nor that of their eggs. The interest for us, however, is connected with the fact that the blood drawn from a given animal may be infected with some form of Haemamoeba (cf p 35) which will give rise to gametes in the digestive tract. These conjugate and then the zygote bores its way into the body-cavity where it encysts The spores produced within the cyst give rise to the original form, and travel to the salivary glands whence they pass down the biting apparatus

into the blood of the next victim. The disease malaria, for instance, is spread in this way by means of a gnat, Anopheles, a near relative of the more common Culex.

The eggs of Culex are laid during the summer in little boat-shaped clusters which float at the surface of still water, ponds, ditches, or even water-butts. The larva is a tiny worm-like organism. It hangs head-downwards

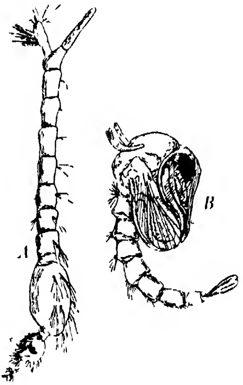


FIG. 50. A Larva of Culex. B. Pupa of Culex (From Miall)

from the surface of the water by a prolongation of the eighth abdominal segment, at the extremity of which open the two principal tracheae. The head is thus well into the water, and the tufts of setae with which it is adorned constantly waft food particles into the mouth. Occasionally, the larva leaves the surface and sinks to the bottom of the ditch, but it soon returns to its old position, working its way up, tail foremost, by a series of jerks ; as it breathes air and has its respiratory pores at the hind end of the body, this must necessarily be in contact with the atmosphere. After three or four moults the larva becomes a pupa. The pupa still hangs from the surface, but now

the head, or rather the thorax, for the anterior part of the body is curved so that the head is bent downwards, is uppermost; and the tracheae communicate with the exterior by means of two 'horns' borne just behind the head, with openings reaching to the air and fringed with setae to prevent ingress of water. The curved thorax forms a bulky anterior mass, and makes the abdomen look long and thin: quite at its end is a pair of flat processes which form a terminal fin or swimming organ. The pupa does not feed, indeed it cannot, for the digestive tract, like all the other internal organs of the larva, is undergoing disintegration to be re-formed upon the adult plan. When the gnat is fully grown and ready to escape, the reason for the position of the pupa becomes apparent, for the skin splits along the dorsal line of the thorax just where it touches the surface of the water, and so the perfect insect slips into the air without any chance of getting wet.

Great efforts are being made just now in tropical countries to exterminate the gnat, on account of its energy in the spread of disease. It is evident that its early aquatic habit is in favour of its suppression, for the drainage of ditches and marshes deprives the adult of places for egg-laying; or treatment of stagnant pools with paraffin oil destroys both larvae and pupae by forming an oily layer over the surface of the water and so preventing access of air to the respiratory tubes. The cultivation of certain fish which prey upon the immature forms, and might, therefore, be introduced with advantage into infected districts, is now under consideration.

CHAPTER XV

THE ANATOMY OF THE DOGFISH

(*Scyllium canicula*)

THE name 'dogfish' has been given rather indiscriminately to certain of the smaller sharks on account of their associating themselves in packs for the pursuit of prey. The sharks, several of which are known on British coasts, are predaceous animals, and dogfish are not the least so. They have a wide distribution in both Old and New Worlds, and appear to be universally hated by fishermen, not only on account of their wholesale destruction of fry and small fish for food, but also because of the injury which some of them work upon lines and nets bait, hooks, and cord are carried bodily away from the former, whilst the latter may be so torn as to be almost useless The dogfish is not often seen in the English market, although it is eaten abroad and might well take a place among food fish in this country: the flesh is very white, but dry and rather fibrous The rough skin forms 'shagreen', used for polishing in cabinet work in China the fins are employed in the manufacture of gelatine, and in British Columbia the fish is prized on account of the oil derived from its liver. This oil was formerly used for barter among the natives, and is now exported by the white population as 'cod-liver oil'

Like the crayfish, the dogfish is aquatic, and hence the two animals resemble one another in those characters which specially fit them for a life in water for instance, in both the body is moved by the action of the hinder region, the flexible abdomen in the one, and the muscular tail in the other, a method of locomotion impossible to imagine in a land form, again, respiration is effected by means of gills requiring to be constantly bathed in water. Such points of resemblance are, however, clearly adaptive, and do not indicate that true similarity which would arise from a common ancestry. The differences between

the two forms are, on the other hand, fundamental, and show how widely distinct are the lines of descent of the animals. The segmentation which is so marked a feature of the crayfish does not show at all on the outside of the dogfish, and though the latter displays an exoskeleton, it is in the form of tiny tooth-like scales, which have no connexion with the muscles, the real supporting structure of the body being a complicated endoskeleton which lies within the musculature. Again, the gills are not outgrowths of the integument, but are derived from the inner tissues the wall of the pharynx is pierced by clefts which put that cavity into communication with the exterior, and the gills are outgrowths of its lining. Then the nerve-cord, instead of being double and solid, and lying on the ventral side of the body, is single, hollow, and dorsal, and the eye, or by far the greater part of it, is formed as an outgrowth of the front portion of this tube This front part is differentiated to form a very complicated region called the brain, the hind portion retaining the primitive condition of a cord. The endoskeleton originates as a cellular rod, the notochord, lying along the body immediately beneath the nerve-cord, but this is replaced in the adult fish by a stronger and firmer structure, which consists of a series of skeletal pieces called vertebrae, the whole series being known as the vertebral column, or backbone Around and in front of the anterior tip of the notochord is developed an elaborate protection for the brain, the brain-case, or skull, while upgrowths from the vertebrae form a defence for the rest of the nerve-cord Skeletal rods give support to the limbs, and through the intervention of the limb-girdles come into relation with this central or axial skeleton. The possession, at some period of development, of a notochord, of gill-clefts, of a dorsal tubular nerve-cord, and of an eye derived from the nerve-cord, characterizes many animals of organization both higher and lower than that of the dogfish, and all exhibiting them are called Vertebrates, from the presence of the vertebrae. In spite, however, of these common characters, the Vertebrates differ among themselves to a very great extent, and so smaller divisions have been established to include animals which display such differences as separate them from other members of the large group. These divisions are. (1) the Pisces or Fishes, including aquatic

animals which possess fins and breathe throughout life by means of gills; the dogfish is a good example of such forms. (ii) The Amphibia, a class constituted for the frog and its allies, fitted by their structure for an amphibious life, i.e. on land as well as in water. Although most of them spend their adult life as air-breathers, they generally pass their early days in water. They are marked off from the fishes by the possession of five-toed limbs instead of paired fins. (iii) The Reptilia, comprising lizards, snakes, crocodiles, and turtles. These are terrestrial animals covered all over with scales, having short five-toed legs and breathing always by means of lungs (iv) The Aves or Birds, covered over with feathers, and having their fore-limbs modified to form flying organs or wings (v) The Mammalia, sometimes called Quadrupeds, covered with hair, and having highly specialized skin glands of various kinds, from one of which, the mammary or milk glands, they take their name

That the dogfish is an aquatic animal may be learnt even by an inspection of its external features. The body is elongate, though bulky and tough, and the bulk is due chiefly to the great development of the muscles The head region is somewhat flattened dorsoventrally, and compressed laterally from the shoulder backwards. Further height is given to the posterior region by the presence of four unpaired fins, two upon the mid-dorsal line, one ventral, and one encircling the tail (Fig. 51, *c.f.*, *d f*, *v f*). Paired fins are also present, the pectorals (*pec f*), close to the posterior gill slit, and the pelvics (*pel f*) further back, bounding the anterior and lateral borders of the excurrent or cloacal aperture Such a shape is evidently suited to cutting a way through water. in swimming, the powerful muscles, and especially those of the tail, come into play, the body being bent first to one side and then to the other, and so forced onwards, as a steamer is driven by its screw. The paired fins seem to serve simply as balancers to keep the animal upright in the water, while the unpaired fins perform the function of keels, and keep it to its course. In colour, the fish is of a brownish-grey shading to almost white on the underside, while the back is marked by irregular spots of a

more decided brown. This coloration renders the animal inconspicuous in the sea, for when viewed from above it tones in with the bottom, and from below the white cannot be seen against illuminated water and a bright sky. Again the gill clefts (*g sl.*) may be seen as a series of five slits on either side, just in front of the pectoral fins, and the water which has passed over the gills finds its way out through them. In front of the first cleft, and close to the posterior extremity of the eye, is a small round hole, the spiracle, which represents yet another slit.

Other points in the external appearance may be mentioned here, though they do not indicate an aquatic life. The whole surface of the body is rough, owing to the spines borne by the tiny scales of the exoskeleton (p. 133); the points of the spines are turned backwards, so that there is a perceptible difference between an 'up' and a 'down' stroke on the skin. The mouth is ventral and lies at some little distance from the tip of the snout, it is large and crescent-shaped, and furnished with numerous sharp-pointed teeth. The position of the mouth makes it necessary for the animal, like all sharks, to turn over on its back before it can seize its prey. From either side of the mouth, a groove, the naso-buccal groove, runs forward to the nostril of that side, a roundish hole, from the inner borders of which a flap of skin arises, to be continued over the groove, so as partially to conceal it The eyes lie on the side of the head they are elongate and slit-like, and protected by upper and lower eyelids, which are simple folds of skin, and not movable. Besides the mouth and the opening of the cloaca there are two other apertures on the outside of the body, these are the abdominal pores lying on either side of the cloacal aperture, and putting the coelom into direct communication with the exterior. In the male dogfish the inner borders of the pelvic fins are modified to form stout rod-like processes, called claspers, which are important in effecting the transmission of the spermatozoa The caudal fin is elongate and bilobed, with the upper smaller than the lower part: this is due to an upward turn of the extremity of the vertebral column, which thus divides the fin unequally.

The flexibility of the body indicates that the endoskeleton must be jointed, and we find, in fact, that the

various hard parts move upon their neighbours in much the same way as do the skeletal plates of the crayfish; but, again as in the crayfish, there is considerable fusion of skeletal pieces in some regions. The usual idea of a skeleton is that it is made of bone, and is hard and rather brittle in the dogfish there is no bone at all, but a softer and tougher material called cartilage In the higher Vertebrates much of the skeleton is laid down in early life in cartilage, to be replaced by bone as the animal develops, in a few forms, of which the dogfish is one, the permanent skeleton consists only of cartilage, which, however, becomes so impregnated with lime-salts as to attain a considerable degree of hardness. The skeleton consists of axial or central, and appendicular or dependent parts: the axial skeleton comprises the skull, and the backbone or vertebral column, the appendicular skeleton is that of the limbs and their girdles The skull is oblong in shape, and includes, besides the cranium, or brain-case, the capsules protecting the olfactory and auditory organs, and a special series of complicated cartilaginous rods, which form a support for the gills, and are known as the visceral skeleton. The cranium is hollowed out at the sides to form a cavity, called the orbit, for the reception of the eye. Posteriorly is a large aperture called the foramen magnum, through which the end of the brain passes to be continued as the spinal cord The sensory capsules are fused on to the skull, and so constitute immovable joints, a joint of this kind occurs also where the jaws of either side meet in front, but as the identity of each part is still clear, the junction is known as a symphysis, and not as a fusion The jaws and the six segmented bars of cartilage which support and separate the gill-clefts on either side constitute the visceral skeleton. The upper segment of the first of these assists (Fig. 52, *hym*) in attaching the jaws to the skull, the attachment having the form of fibrous bands, and thus giving a movable joint The four posterior pairs of bars have a common basal portion. The supports for the gills are rod-like pieces of cartilage projecting as a fringe from the posterior aspect of each bar. The vertebral column is made up of a number of separate pieces, the vertebrae, which as well as giving support to the musculature, and hence to the body generally, afford, by means of a series of dorsal processes, a protection

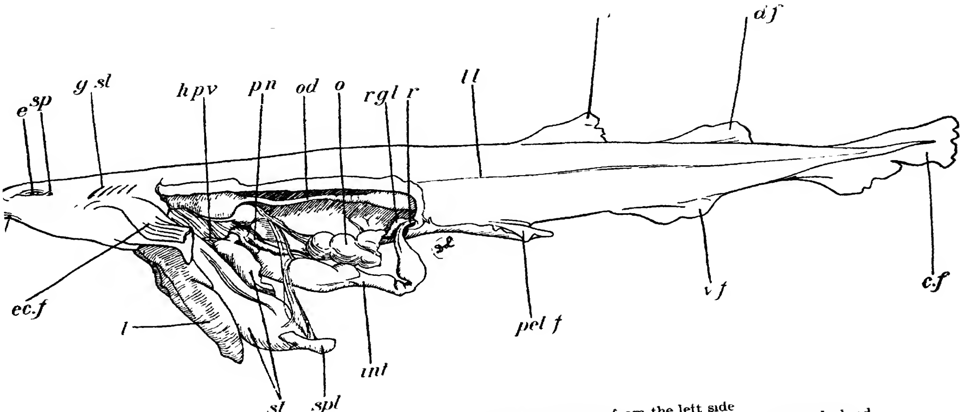


FIG 51. General dissection of a female dogfish as seen from the left side

c.f caudal fin.
d.f dorsal fin
e eye
g.sl gill-slit
h p v. hepatic portal vein.
int intestine
l liver
l l lateral line.
m mouth
n nostril
o ovary.
od oviduct
pec f pectoral fin.
pel f pelvic fin
pn. pancreas
r. rectum
r gl. rectal gland
sp spiracle.
spl spleen.
st. stomach.
v.f. ventral fin.

for the spinal cord (p. 133). There is a series of ventral pieces also, which, in the trunk region, extend horizontally and give attachment for the ribs, while in the tail they become vertical, and enclose a space for the passage of the artery and vein of this region. The main part of the vertebra is known as its body or centrum: this is a cylindrical piece of cartilage so thickened within as to be something like a dice-box, the cavities at its end being filled with a mass of soft tissue, the remains of the notochord. Successive centra are fastened together by fibrous junctions (cf attachment of the jaws to the skull) so that a certain amount of movement of one upon the other is possible. The dorsal and ventral arches of each vertebra are fused to the centrum and the supporting rays of the median fins come into relation with the arches The lateral fins are attached, each pair, to a stout cartilage, which forms the pectoral (shoulder) or pelvic (hip) girdle, as the case may be The pectoral girdle, which lies just behind the head, does not form a complete ring, but is open dorsally, the terminal portions being curved inwards and backwards over the vertebral column. To support the limb itself, there are three stout basal cartilages attached to the girdle (Fig. 52, b^{i}, b^{ii}, b^{iii}), with a series of smaller pieces radiating from them, while a fringe of fine horny rays (h) extends to the margin of the fin The pelvic girdle is simply a stout bar of cartilage lying ventral to the vertebrae there is only one basal piece here, and the radials, fourteen in number, lie along its outer edge The fins are attached to the girdles by firmer and stronger joints than any of those yet noticed, the girdle bears a special facet for each corresponding basal cartilage of its fin, and so a true articulation is formed.

Where joints of this kind occur, the necessity for a specialized musculature is obvious. The muscles in the dorsal region of the trunk and in the tail are divided by fibrous septa into metameric segments. These segments are equal in number to the vertebrae, but alternate with them so that each is attached to the halves of two vertebrae, and in this way causes the movement of the fibrous junction. On the ventral side of the trunk the segmentation is not retained, the muscle-bundles give place to longitudinal

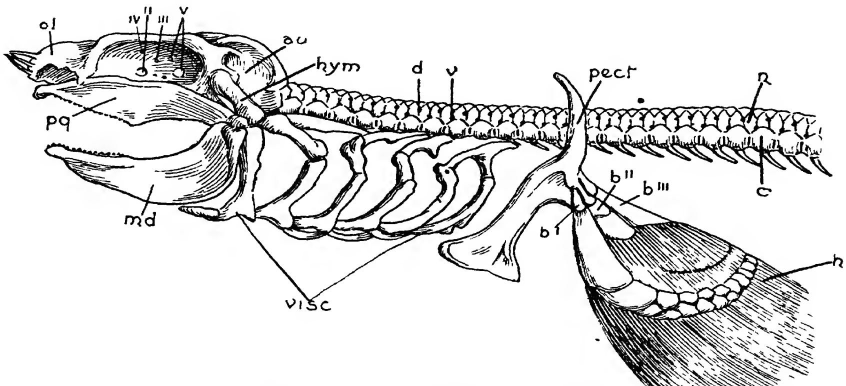


Fig 52 Part of the skeleton of the dogfish

au auditory capsule b^{i}, b^{ii}, b^{iii} basal cartilages of pectoral fin. *c* centrum of vertebra *d* hole for exit of dorsal root of spinal nerve *h.* horny rays of fin *hym.* part of visceral skeleton supporting lower jaw *md* lower jaw. *n.* dorsal process of vertebra. *ol* olfactory capsule *pq* upper jaw *pect.* pectoral girdle *v* hole for exit of ventral root of spinal nerve *visc* visceral skeleton. ii, iii, iv, v. holes for exit of cranial nerves

sheets. The head, the limbs, the gill-clefts and mouth, in fact all those parts of the body furnished with movable joints, have each their own specially developed muscle-supply

The muscles, like every other part of the body, are under the control of the nervous system, which, as in the earthworm and the crayfish, sends its branches to every tissue and organ. It may be well to call attention again to the difference in the position of the nerve-cord in the dogfish and in the lower animals in the latter it is ventral, but here it is dorsal, a difference which not only affects the relative positions of all the other organs, but also an investigation of them, in dissecting Lumbricus or Astacus, one must work from the dorsal side of the animal; in Scyllium from the ventral aspect.

The brain and spinal cord, which are protected by the cranium and the dorsal arches of the vertebral column (p 133), are further covered by a membrane whose numerous vessels give the blood-supply The membrane lies close to the nervous mass and penetrates the crevices and folds, even dipping, in some cases, into the hollow of the tube The space between the membrane and the protecting case is filled with a liquid called lymph, about which more will be said later. The brain falls naturally into three regions, the fore, mid, and hind brains The fore brain, the most anterior part, is flattened and somewhat triangular, it exhibits raised and rounded masses, the cerebral hemispheres (Fig 53, *cer*) in front, and a flatter portion, the thalamencephalon behind this bears upon its roof a small outgrowth, the pineal body (*p*), which is connected in some animals (certain fish, lizards) with the top of the head, where there is a third, functionless eye. From the floor of this region projects a hollow process, the infundibulum, beneath and behind which lies a small tubular mass, the pituitary body At its anterior angles the forebrain widens out into massive olfactory lobes (*olf l.*) which are in close relation with the olfactory capsules (*olf c*), and send nerves into them. The mid-brain is wider than the thalamencephalon, and is divided by a deep cleft into the corpora bigemina, or optic lobes (*op.l.*), but these are almost concealed by the expansion of the cerebellum (*cbm.*) a large oval body extending over

the neighbouring parts both before and behind, and, with the medulla oblongata (*med.*), making up the hind-brain. The medulla passes evenly back into the spinal cord, which is flattened dorso-ventrally and exhibits a

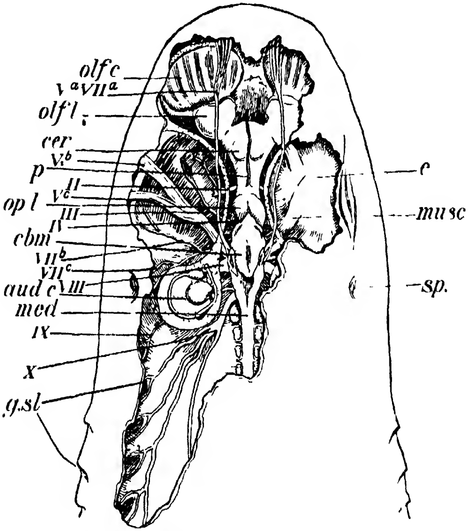


FIG 53 Dissection of the brain from the dorsal side. I to X cranial nerves

aud c auditory capsule
cbm. cerebellum
cer. cerebrum
e. eye
g sl gill-slits
med medulla
musc muscles of eyeball
olf c olfactory capsule
olf l olfactory lobe
op l optic lobe
sp spiracle
p pineal body

groove upon each flattened face it is traversed by the central canal, which is continued in front into the cavities or ventricles of the brain. Nerves are given off in pairs, somewhat irregularly from the brain, metamerically from

the cord. The cranial nerves supply only the organs of special sense and the muscles of the head with the exception of the tenth, which sends a branch to the internal organs. All but the fourth pair, which is dorsal, come off ventrally or laterally. From the cord they arise by two roots, dorsal and ventral; the dorsal roots are afferent or sensory, carrying impressions inwards; they display a ganglion near the point of origin: the ventral roots are motor or efferent, and transmit impulses to the appropriate muscles. Dorsal and ventral roots pass out of the spinal canal through separate holes in the plates between adjacent vertebrae, and then unite to form one trunk their arrangement, therefore, corresponds with the segmentation of the muscles, and they alternate with the segments of the backbone.

The sense organs are highly specialized: optic, auditory, and olfactory organs are well developed; there are numerous groups of sensory cells in the neighbourhood of the mouth, which may have a gustatory function, and tactile impressions of some kind would seem to be received by nerve-endings contained in the mucous canals of the head and of the lateral line. If the head of a dogfish be gently pressed with a movement from behind forwards, beads of mucus will appear in regular lines about its dorsal surface. This mucus is secreted in canals beneath the skin, and finds exit through numerous pores; a similar canal, the lateral line, extends along either side of the body. All these canals have a rich nerve-supply in connexion with groups of sense cells which occur at regular intervals along their course. It is probable that the entire system has to do with the appreciation of currents, whether produced by winds or by the presence of larger aquatic animals. The auditory organ is a specialized part of this mucous canal system. It is a membranous sac of complicated structure, known as the membranous labyrinth (Fig. 54). It has patches of sensory cells upon its walls, and is lodged in a cavity in the cartilage of the hinder part of the skull, called the cartilaginous labyrinth. The organ falls roughly into two parts; of these the upper, or utriculus, gives origin to three semicircular canals, which lie in planes at right angles to each other in the three dimensions of space, while the lower, or sacculus, is provided with a short appendage, the lagena: the two parts are connected by a narrow

tube. From the utriculus a canal, the ductus endolymphaticus, runs to the surface of the head, where it opens by a pore. The membranous labyrinth contains a fluid called endolymph, in which, in the neighbourhood of the sensory patches, are little masses of carbonate of lime, the otoliths (cf. the grains of sand in the 'auditory' sac of the crayfish, p. 124). How far the fish can hear, in our sense of the word, is very doubtful. Probably the organ, like the rest of the canal system, appreciates vibrations without

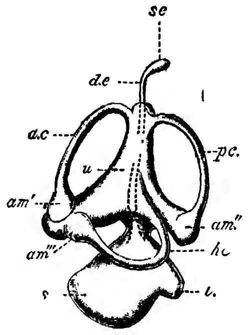


FIG. 54 Ear of fish. (From Wiedersheim)

a c., hc, pc semicircular canals — l lagena
am'., am'', am'''. enlargments of canals. — s. sacculus
d e, s e ductus endolymphaticus — u utriculus

any great definiteness, for there is no communication with the exterior except by the pore of the ductus endolymphaticus: the semicircular canals have to do with the sense of direction and the maintenance of equilibrium. The olfactory organs are well developed. Each capsule is somewhat oblong in shape, and is strengthened as to its outer wall by cartilaginous supports, and provided with cartilaginous septa, which radiate inwards from the wall; the septa are covered with a skin which bears the sensory cells. All these organs are derived from the superficial layers of the body and come into relation with the brain later by means of sensory nerves. With the eye, however,

the case is different the very great part of this is a true outgrowth from the brain, to which it remains attached by the optic nerve. The fibres of this nerve cross on the underside of the brain, so that the right eye is supplied by fibres from the left side of the brain and vice versa. The eye (Fig 55) is somewhat hemispherical in shape, flattened in front and convex behind, the optic nerve makes its entrance obliquely at about the middle of the inner side of the eyeball The wall consists of several

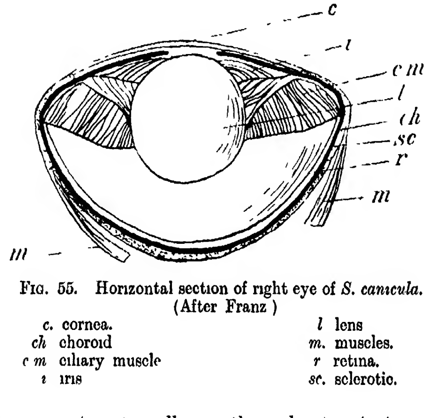


FIG. 55. Horizontal section of right eye of *S. canicula.* (After Franz)

c. cornea.	*l* lens
ch choroid	*m.* muscles.
c m ciliary muscle	*r* retina.
i iris	*sc.* sclerotic.

layers. most externally is the sclerotic (*sc.*), a thick whitish coat, rendered firmer by the presence of cartilaginous plates; in front it is continued into a transparent, flattened area, the cornea (*c*), which is clothed externally by a delicate extension of the skin of the head, called the conjunctiva; posteriorly the sclerotic is continued as the sheath of the optic nerve. Within is the choroid coat (*ch.*), which is very vascular, and most internally is the perceptive layer, the retina (*r*), which is somewhat transparent and consists of perceptive bodies, the rods and cones, set close to one another and coming into relation with the fibres of the optic nerve. The point of entry of the nerve is not sensitive to light, and is therefore known as the blind

spot. In front of the eye, immediately beneath the cornea, is the lens (*l*) which causes the rays of light to converge to a point, and thus to throw an image on the retina. In the dogfish the lens is globular, and therefore the animal must be near-sighted, as only rays from objects near at hand will fall exactly upon the visual elements, and there is no apparatus for accommodation, i.e. for altering the focus. The lens is kept in position by two forward extensions of the choroid. that nearer the retina constitutes the ciliary folds (*c.m.*), while that next the cornea forms the iris (*i*), a pigmented membrane with a central aperture, the pupil, for the passage of light. The lens is large and touches the cornea, also almost fills up the space in the eyeball. what is left is occupied by a gelatinous mass called the vitreous humour. The eye consists, broadly speaking, like the eye of the crayfish (p. 125) of a refractive part (here the lens) and a perceptive part (the retina); but whereas the eye of the crayfish is compounded of numerous little eye elements, each apparently complete in itself, and able to see only a minute portion of any object, that of the dogfish, with all its parts co-ordinated to form one optic body, visualizes the object as an entire picture.

By far the greater part of the coelom in Scyllium forms the abdominal cavity, but there is also a small anterior part, in front of the pectoral girdle, called, as it contains the heart, the pericardium. The two divisions of the coelom are in communication by means of the pericardio-peritoneal canal of either side. They are lined with a membrane which is known in the abdomen as the peritoneum. The abdominal organs really lie dorsal to the peritoneum; but the alimentary canal, for example, comes away from the dorsal wall and drags the lining with it, so that it is covered by a single, and is attached to the wall by a double, fold of the peritoneum. In the adult the fold has formed a single layer by coalescence, and is incomplete in many places.

The alimentary canal is, as usual, a tube running the entire length of the trunk; it is bent once upon itself in the middle of its course, and then passes straight on to its termination (Fig. 51). The ventral mouth opens into the buccal cavity, a wide chamber, which is not clearly

marked off from the pharynx. The presence of teeth upon the jaws has been already referred to. The mouth is really lined by an extension of the ordinary skin of the body, and the teeth are merely somewhat enlarged scales. The simple scale of the outer integument consists of a squarish hollow basal plate, formed of a hard substance something like bone, called dentine. This plate is sunk in the skin, and only its sharp spine, which bears a cap of very hard material, called enamel, is visible. In the mouth the scales, or teeth, are restricted to the membrane covering the jaws, and are large and sharply pointed, with their points standing up from the edge of the jaw. Several rows are present upon the inner side of the jaw, with their points turned down; as the teeth actually in use become worn they fall off, and are replaced by those of the next row, which come into position as the old ones are shed. On the floor of the mouth is a small, flat, immovable tongue, the pharynx is shallow and wide, and is pierced on each lateral wall by six perforations, the spiracle and the gill-clefts The oesophagus, though much narrower than the pharynx, is wide and short, and with it the alimentary canal enters the abdominal cavity. The stomach (Fig. 51, *st.*), which is bent upon itself, is wide in the proximal limb, but narrows very considerably in the distal part, or pylorus, where it gives place to the intestine. A dark red, lobed body is attached to the outer end of the bend and runs forward almost to the intestine (*spl.*): this is the spleen, an organ connected rather with the blood vascular than with the digestive system, although its position requires that it should be mentioned here. Attached to the inner aspect of the stomach is another organ, the pancreas, also lobed, but pale yellow in colour (*pn.*), it is a glandular structure whose secretion, a digestive liquid, is poured into the canal just below the pylorus. The liver (*l*), another digestive gland, large and three-lobed, lies ventral to the stomach in front of the pancreas, and secretes a liquid called bile The bile is stored in the gall-bladder which is embedded in the substance of the gland, and is emptied by the bile duct, which opens into the alimentary canal a little behind the orifice of the pancreatic duct. The middle part of the intestine is marked upon the outside by traces of

a spiral line, which indicates the presence within of the spiral valve, a membranous fold which serves to increase the absorptive surface of this region, just as the typhlosole increases the surface of the intestine in the earthworm. The narrow hindmost part of the canal, the rectum (*r*), is furnished with a small finger-shaped gland (*r.gl.*), and discharges posteriorly into a chamber opening to the exterior, which receives also the ducts of the excretory and reproductive organs, and is known as the cloaca.

As in the earthworm and the crayfish, the products of digestion are absorbed from the intestine and distributed to the various organs by the blood vascular system. Blood from the digestive tract is carried to the liver by the hepatic portal vein (Fig. 51 and 56, *h.p.v.*), and after traversing this gland and losing some of its stores, passes by the hepatic vein to the heart. The heart is really a tube bent twice upon itself, and divided into four continuous chambers: most ventrally is the ventricle, a large somewhat triangular sac with very muscular walls, narrowing anteriorly into the truncus arteriosus, which is partly covered over by a glandular mass, the thyroid. Above and behind the ventricle, and opening into it by a wide aperture, is the auricle, a thin-walled chamber communicating posteriorly with the fourth compartment, the sinus venosus. The ventricle is the active part of the heart; its powerful contractions are responsible for pumping blood all over the body. In all Vertebrates the ventricle performs this most important function, and its strongly muscular walls are always in marked contrast to the thin walls of the auricle. Venous blood, not only from the liver, but also from the whole body, arrives at last at the sinus venosus, and is passed on by the rhythmical contraction of the heart to the auricle and the ventricle, whence it is pumped into the truncus arteriosus. The truncus (Fig. 56, *t.a.*) gives off vessels right and left to the gills: it is furnished with transverse rows of watch-pocket valves, which allow a free passage of blood from the heart, i.e. to the arteries (cf. p. 118), but effectually prevent a back-rush to the ventricle, this definite flow standing in marked contrast to the conditions in the crayfish, where the blood leaves the heart in many directions (p. 118). The afferent arteries from the truncus to the gills break

up into capillaries, each in its own set of gill-filaments, and so allow the respiratory exchange to take place, oxygen being taken in from the water, carbon dioxide going out from the blood. From the gills, the efferent arteries run backwards and upwards to form a stout vessel, the dorsal aorta, which traverses the entire length of the animal. The first efferent artery supplies the head, and the body generally is served by vessels derived from the dorsal aorta Paired arteries go to each pair of muscle segments (p. 138), to the lateral fins, and to the excretory organs or kidneys (*s c a.*, *p a.*, *r.a.*); and besides these there is a series of single arteries to the digestive tract and the reproductive organs (*cl.a* , *a.m.a.*, *lg.a* , *p.m.a.*). Towards the tail the dorsal aorta is continued as the caudal artery. Veins are represented by a system of sinuses; these are distensible blood spaces with very thin walls, quite distinct, however, from the body cavity, and therefore altogether different in position from the sinuses of the crayfish; they all discharge ultimately into the sinus venosus. Special mention must be made of the blood supply of the liver, and of the kidneys These organs, like all other parts of the body, receive blood from an artery which breaks up into capillaries; but each is also served by a vein and this vein forms a capillary system too. We have noted that blood from the intestine is taken to the liver by the hepatic portal vein, and after traversing the capillaries goes on to the heart by the hepatic sinus (*h.v.*); in the same way, blood which is being returned from the hinder end of the body is taken to the kidneys by the renal portal vein, which breaks up into capillaries in the substance of the organ, these tiny vessels uniting up to form the renal veins which discharge into the posterior cardinals (*p.c v.*) and so into the sinus venosus. The intercalation of a mass of capillaries in this way upon the course of a vein is known as a portal system, renal portal in the kidney, hepatic portal in the liver; the latter occurs in all the higher animals, the former only in certain groups.

Blood from the truncus arteriosus is carried by the afferent branchial arteries to the gills, and travels through the capillaries of these organs. The gills are situated in pouches lying on either side of the pharynx (p. 146)

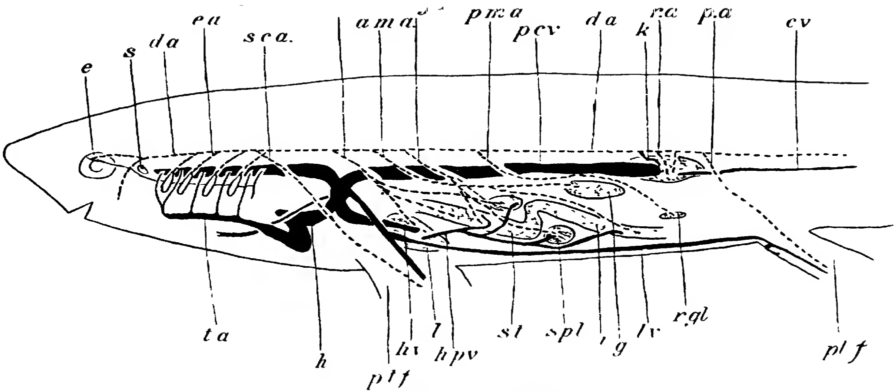


FIG 56 Diagram of vascular system

a m a anterior mesenteric vein
cl a coeliac artery
c v caudal vein
d a dorsal aorta
e eye
e a. afferent branchial artery
g gonad
h heart
h p v. hepatic portal vein.
h v hepatic vein.
i intestine
l liver
lg a lienogastric artery
l v lateral vein
p a pelvic artery
p c v posterior cardinal vein.
pl f pelvic fin
p m a posterior mesenteric artery
pt f pectoral fin
r a renal artery
r gl. rectal gland.
s spiracle
s c a. subclavian artery.
spl. spleen.
st. stomach
t a. truncus arteriosus.

and opening into it on the one side and to the exterior on the other the pouches are supported by the visceral skeleton (p 136). The gills themselves are very vascular and are much-folded extensions of the mucous membrane lining the pharynx · they are attached to the branchial bars with the folds directed outwards upon the septa. A complete gill consists of the folds adherent to both sides of an arch, those upon one side being known as a hemibranch. Hemibranchs occur on the anterior side of the first pouch, and the posterior wall of the last, a rudimentary gill or pseudo-branch projects, into the cavity of the spiracle Water is taken in by the mouth and finds its way through the slits, passing over the gills on its way thus oxygen is sent to the gills and so enters the vascular system, carbon dioxide passing out at the same time

An important point will have been noticed in this description of the vascular supply of the gills that blood from the body generally, i e venous blood, is taken to the heart before it goes to the gills to be oxygenated It follows, therefore, that the blood in the heart is venous, and that arterial blood never enters its cavity (the substance of the heart is, like any other muscular tissue, supplied with arterial blood), so that the great arterial trunk from the heart towards the gills carries venous blood. This is in complete contrast to the condition of things in Astacus, where venous blood from the body goes to the gills, is charged with oxygen, and then transmitted to the heart, which thus receives arterial blood, and that only The blood of Scyllium, like that of Lumbricus, is tinted red with haemoglobin, but the similarity does not go further · the haemoglobin in the dogfish, as in all Vertebrates, is lodged in corpuscles, which are thus red, while the plasma in which they float is colourless There are also white corpuscles, which are in all respects comparable with those of Lumbricus the red corpuscles of the dogfish are oval, biconvex bodies, with large nuclei

The blood is the great carrier of food and oxygen to all parts of the body each tissue obtains what it requires from the capillaries with which it is supplied, the plasma exuding through the walls (which are only a single cell in thickness), and the white corpuscles, which remove

deleterious matters, making their way through also. It is evident that unless some system of drainage were provided to remove the superfluous plasma, the tissues would become as it were, 'water-logged'. Such drainage is afforded by the lymphatics, delicate vessels and sinuses distributed all over the body. The smaller spaces unite to make a few larger spaces, and the lymph, which is really plasma containing white corpuscles, eventually finds its way back into the venous system.

The execretory organs are complicated they consist essentially of coiled tubules, which lie outside (dorsal to) the coelom, covered by the peritoneum At an early stage of development the tubules open by means of funnels into the coelom and throughout life are in connexion with a longitudinal duct, the ureter, which ends in the cloaca. In the male dogfish the kidney is a long, narrow, reddish mass divided into two parts It is the posterior of these only which is the functional excretory organ, comparable, as regards its work, with the nephridia of Lumbricus, or the contractile vacuole of Amoeba. The excretory products are taken from the blood in the renal capillaries and pass to the exterior by means of the ureter In the female animal, the anterior portion of the organ is small and ill-defined, the posterior part is similar to that of the male.

As in Astacus, ovaries and testes are lodged in different individuals. The testes are attached to the dorsal wall of the coelom by peritoneal folds Each is in communication, by means of small ducts, with the tubules of the anterior part of the kidney. These tubules of either side open into a long coiled duct, or vas deferens, which, in its turn, opens into the cloaca. In the female, the single ovary (Fig. 51, *o*) hangs from the dorsal wall of the abdominal cavity by a fold of the mesentery. It is characterized by the presence of ova in various stages of development, the larger ones showing distinctly as rounded projections from the surface The oviducts (*od*) are not connected with the ovary, so that the ova, when ripe, are shed into the body-cavity and find their way forwards to the anterior border of the liver, where lies the single internal aperture of the united ducts. Each duct exhibits a thick-walled dilation near its origin, the oviducal gland, wherein is

secreted chitinous material to form the egg-shell. In the hinder part of the coelom the ducts again unite, and open by a single pore into the cloaca.

The eggs may be compared with those of a bird: there is a great quantity of yolk upon which the developing animal feeds, and a shell for its protection until it is ready to hatch. The shell is deposited in the oviduct, therefore

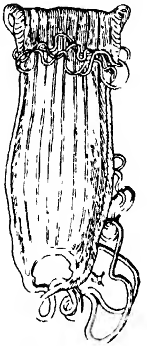


FIG. 57 Egg case

it is impossible that union with the spermatozoon can take place after the egg is laid this process actually occurs far up in the oviduct, the spermatozoa having been introduced by the agency of the claspers (p. 135) The shell is chitinous and quadrangular. When the egg is laid long streamers of the chitinous substance (Fig. 57) project from the corners and serve to moor it to rock, sea-weed, or other foreign object. The little fish undergoes its development within the shell, and leaves it differing from the adult only in point of size

CHAPTER XVI

THE LIFE-HISTORY OF THE FROG

(*Rana temporaria*)

If ponds or ditches or any pieces of still water are visited in early spring, masses of what looks at first sight like rather substantial soap-bubbles may be seen floating at the surface A closer examination discloses that each bubble is a little solid mass of a white jelly-like substance enclosing a tiny black centre. The black 'centres' are frogs' eggs; the 'jelly', a kind of mucus, which covers them; and the whole mass is known as 'spawn'. Frog spawn is rather slippery stuff to handle, but with care a small quantity may be dipped up from the ditch, and with due attention to cleanliness may easily be kept at home in a basin of water, when the eggs may be watched until they hatch out as tadpoles, and the tadpoles while they turn into frogs. Frogs hibernate during the winter, hiding away in holes in the ground, or cavities in a bank either above or below water, as the spring comes round they betake themselves into the pond or ditch and there the eggs are laid. They sink at first, but soon come to the surface again, the mucus, which was deposited as a thin layer during their passage down the oviduct, having become thick and quite transparent, by absorption of water. The spawn usually floats until the hatching of the tadpole, though a disturbance will cause it to sink, without apparently interfering with the course of development; but as warmth is necessary for this process it is evidently an advantage for the eggs to be at the surface, where they have the full benefit of the sun's rays.

The newly-laid egg looks black when viewed from above, but it is only the upper hemisphere which contains pigment; the lower half, in which most of the food-material, or yolk, is stored, is white; soon, however, the pigment extends all over the surface, and the egg elongates and

becomes oval. After about ten days, the embryo shows specialization into head, trunk and tail, and its greater length causes it to be curved round within its mucous envelope. In a fortnight or so it hatches, leaves its protective coverings and becomes a free-swimming larva (p. 79). The general appearance of this larva, or tadpole, as it is generally called, is well-known to most people. It bears a marked resemblance to a fish, and from the first the absence of neck and the long motile tail are very noticeable. When it hatches there is no mouth; the little body hangs to a water-weed by means of a secretion from a glandular mass on the under-surface of the head, and is nourished by the yolk still remaining in the digestive tract, until a mouth furnished with horny jaws breaks through. The animal feeds upon vegetable matters, and in connexion with this kind of diet the digestive tract increases greatly in length Bulk for bulk, green vegetables are far less nutritious than animal food, therefore relatively much larger quantities have to be eaten to give the same amount of nutriment, and a great digestive surface is necessary for the separation of this from the worthless substance Thus a cow or a sheep, which lives entirely on vegetable food, has a much longer and more complicated digestive tract than a dog or a cat, which is flesh-eating, and a tadpole and a frog differ in the same sort of way. At this time the tadpole is breathing by means of the so-called external gills, delicate vascular processes, standing out freely into the water from the dorsal part of the body-wall, just behind the head A little later, four gill-clefts break through from the pharynx on each side, and a second set of gills, the so-called internal gills, appears ventrally along their margins. The first gills wither and are cleared away by the activity of the white blood corpuscles which act as scavengers, just as do the corpuscles in the coelomic fluid of the earthworm (p. 95) While the 'external' gills are still functional, a fold of skin, the operculum, grows over them on either side, the two folds coalescing so as to enclose a single chamber, opening to the exterior on the left side. When the gill-slits are established, the water, taken in by the mouth and passed through the clefts, is received into this chamber, and finds its way out through the pore. All this time the tadpole is steadily

growing bigger, and now the legs are formed. The hind legs show first, because the front ones are concealed by the opercular folds, and the little animal presents a very odd appearance swimming about by means of a strong tail and long legs, with no forelimbs showing at all. Next, air-

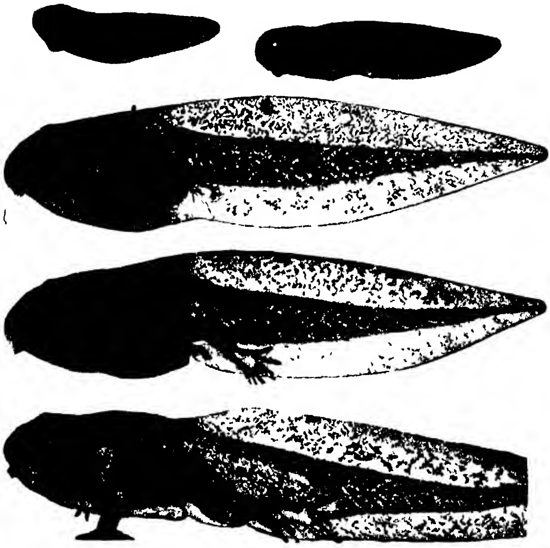


FIG 58 Stages in the life-history of the frog (From Keibel)

breathing organs, the lungs, arise within the body, so that the larva can, for a time, use both these and its gills, and it may be seen occasionally rising to the surface to take in breaths of air. The gills are, however, lost with the change to the adult form. The outer skin of the whole body, including the horny jaws, is thrown off: the forelegs appear, the right bursting through the opercular wall, while the left is thrust through the pore a little later.

the gills atrophy, the clefts close up, and there is a gradual dwindling of the tail, which, as it shrivels, is cleared away like the gills by the white blood corpuscles. The animal is now a little frog, the whole series of changes having taken about three months for their completion. The tadpole may, however, be prevented from achieving this

FIG. 59. *Rana temporaria.* (From Ecker.)

metamorphosis by being kept always under water, so that it has no opportunity of getting to the air. English tadpoles have been kept as larvae during a whole winter, and in certain deep-sided lakes in Mexico there is a well-known form, the Axolotl, which normally undergoes no change, and was for a long time supposed to be an adult animal. Now it is known that if it be given free access to air at the proper time, it will undergo the metamorphosis and become a terrestrial, tailed form.

The changes occurring in the internal organs are quite as great as those to be noted in the external appearance of the animal. The tadpole, with its aquatic habit, strongly developed tail and tail fin, lateral line organs, and functional gill-clefts, is to all intents and purposes a fish; and associated with these external organs there are metameric muscle-bundles, a cartilaginous skeleton, and truly fish-like arrangements in the circulatory and respiratory systems. The frog is, though amphibious (p. 134), yet most evidently a terrestrial form; its legs adapted for walking or jumping, its relatively strong, bony skeleton, its air-breathing respiratory arrangements marking it off distinctly from fish and tadpole, and linking it on to reptiles and mammals. The early condition of some of these organs and the changes which they undergo during metamorphosis will be briefly considered now. The first part of the skeleton to arise is the notochord, around which a continuous sheath soon appears, and outside this the vertebrae are formed, at first as little patches of cartilage, which later grow round the sheath and cause its reduction. After the metamorphosis the cartilage is replaced by bone, but up to that time the vertebral column compares, as regards at least the material of which it is made, with that of Scyllium. The skull is also cartilaginous at first, and consists of cranium, sense capsules, and visceral skeleton, the hinder part of the cranium, with the auditory capsules, embracing the anterior part of the notochord. The visceral skeleton consists of six pairs of arches, the jaws, the hyoids and the four pairs of branchial bars. Later the sense capsules become joined to the cranium, forming fusions with it, and while the jaws become more closely attached in the anterior part, the hyoids and branchial bars are reduced in the adult to form little more than a plate supporting the tongue. Much of the cartilage comes to be replaced by bone, and most of what remains unchanged is covered over by flat sheathing plates called membrane bones. It was noticed in the last chapter that cartilage is a firm 'gristly' substance: it is supplied with blood by the vascular membrane which covers it, and is penetrated neither by vessels nor by nerves. Bone, on the other hand, is hard and brittle; when it replaces cartilage, the latter is raided

by bone cells which eat it away, depositing hard substance in its place. The cells remain in little cavities within the bone, which is further invaded by blood-vessels and nerves. Bone formed in this way is known as cartilage-bone. membrane bones are formed by the deposition of the hard substance as flat plates beneath membranes.

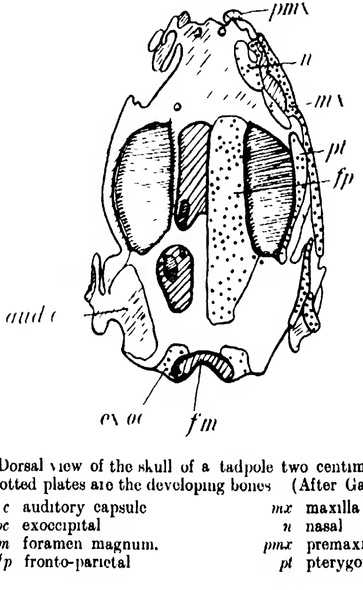


FIG. 60. Dorsal view of the skull of a tadpole two centimetres long. The dotted plates are the developing bones (After Gaupp.)

aud c	auditory capsule	*mx*	maxilla
ex oc	exoccipital	*n*	nasal
f m	foramen magnum.	*pmx*	premaxilla.
fp	fronto-parietal	*pt*	pterygoid

The segmental arrangement of the muscles is well seen in the tail, and again in the dorsal region of the trunk; as in the dogfish, the ventral trunk muscles have lost their primitive relations. As development proceeds and the disappearance of the tail is complete, the trunk muscles come to be arranged chiefly in large sheets, while those of the limbs are more or less spindle-shaped, their tapering

ends often forming cords, called tendons, for attachment to the joints which they move.

The heart of the embryo is literally a bent tube, but by the time that the tadpole is breathing by internal gills it has much the same structure as that of the dogfish. It consists of sinus venosus, auricle, ventricle, and truncus arteriosus; the truncus gives off a series of four vascular arches on either side, one to each of the gill-clefts (in

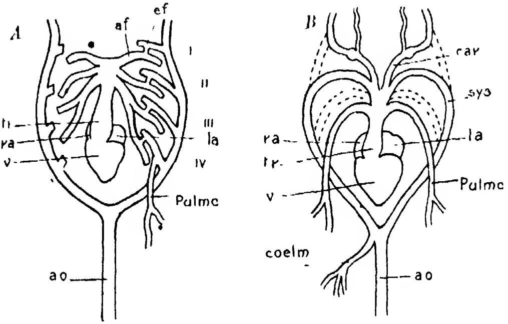


FIG. 61 Heart and arterial arches of A, a tadpole, B, a frog.

af.	afferent branchial artery	*pulmc*	pulmocutaneous artery.
ao.	aorta	*r.a.*	right auricle
car.	carotid artery.	*sys*	systemic artery
coelm	coeliaco-mesenteric artery	*tr.*	truncus arteriosus
ef	efferent branchial artery.	*v*	ventricle
l a.	left auricle	i, ii, iii, iv	branchial arches

Scyllium, it will be remembered, there are five such arches). The efferent branchial vessels, as might be expected, unite to form the dorsal aorta, and venous blood from the whole body is returned to the sinus With the establishment of the lungs, pulmonary arteries are given off from the fourth arch and carry away some of the blood; soon a junction is made between each afferent and its corresponding efferent vessel, so that more of the blood from the heart goes direct to the lungs, avoiding the gills altogether. As the gills dwindle, still less blood goes to them, and at the same time the lungs enlarge greatly and more blood

passes on to the pulmonary artery, which soon gives off a branch to the skin. At the final change the first of these four arches is known as the carotid artery; the second, the systemic, the third has disappeared, and the fourth is the pulmo-cutaneous. Now the blood is returned to the heart from the lungs, and the auricle becomes divided by a septum into a left half, which receives the arterialized blood from the pulmonary veins, and a right, into which is poured venous blood from the sinus. In the adult frog this condition of things persists; venous blood is restricted to the right auricle, arterial blood to the left, but the two kinds are received by the single ventricle, whence they are pumped over the body, a special arrangement of the openings of the arteries, aided by a special development of valves, ensuring that arterial blood alone shall go by the carotid arteries to the head, mixed blood by the systemic arches to the body, and venous blood by the pulmo-cutaneous arteries to the lungs and skin. The skin, from the absence of exoskeleton and the presence of very numerous glands, recalls that of the earthworm, and assists materially in the respiratory function. The lungs, two in number, are vascular, thin-walled sacs, whose inner lining is thrown into folds, so as to form many tiny chambers, freely open to the main cavity of the organ in this way the inner surface of the lung is greatly increased and a large vascular area is exposed to the outer air, for the cavity communicates with the mouth, and so with the exterior. Next to the rich vascular supply, the elastic natur of the lungs is their chief characteristic. This is clearl seen when they are inflated, and swollen up like bladders for they collapse very readily when the elasticity comes into play and air is driven out. The mechanism of respiration in the frog is so different from our own as to deserve a few lines of explanation. If a resting frog be watched, the floor of the mouth, or rather the skin under the throat, will be seen to move up and down constantly, while the mouth keeps tightly shut. The frog cannot, indeed, breathe with its mouth open, but the lowering of the floor make the buccal cavity larger, hence the pressure of air within is less than that without, and so to equalize the pressur air rushes in through the open nostrils, which are closed aga at once. In the meantime the air in the lungs is bei

forced out by their contraction; next, the aperture of the windpipe opens to allow this air to get into the mouth, so that there may be some interchange between it and the fresh air which is already there. Then the floor of the mouth rises so that some of the air is forced into the lungs, and with the opening of the nostrils the rest rushes out, just as the floor of the mouth lowers again to make room for a fresh supply.

Another important adaptation to a life on land is the possession of legs, which involves a new mode of loco-

FIG 62. Development of the toed limb. (From Hertwig.)

motion for the animal. The presence of such limbs is characteristic of all animals of organization higher than the fish where fins recur (e.g. turtles, whales) they are formed clearly by modification of the terrestrial walking leg. The tail of the larva, with its median fin passing continuously from the mid-dorsal to the mid-ventral line, is essentially an aquatic organ and its efficiency may readily be determined in any wriggling tadpole. As this tail degenerates, the legs attain their full strength. They appear at first as tiny buds (Fig. 62) projecting from the surface of the body, increase in length, and become jointed until the leg in the adult frog consists of the same parts as, for instance, our own. In each there is an upper

region from shoulder to elbow, or hip to knee; a lower part from elbow to wrist, or from knee to ankle; and a hand or foot as the case may be. In the frog, the hind leg, and particularly the foot, is very long, and with its strongly-developed muscles confers great powers of jumping upon its possessor.

The great length of the digestive tract, when the larva has a vegetarian diet, has been noted (p. 154) the adult

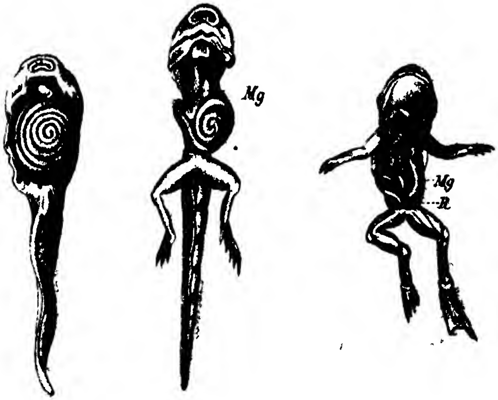


FIG. 63. Development of the intestine (From Reuter) *mg* stomach *r* rectum.

frog feeds on small animals such as flies, slugs, and worms, catching them with its long fleshy tongue, which is attached to the jaw by the front end, and, therefore, when flicked out, has a very long reach As would be expected from the change in the nature of the food, the digestive tract is much shortened at the metamorphosis. The especially long part in the tadpole is the small intestine, i.e. the narrow tube, which immediately follows the stomach

(Fig. 63): it is so very long that, to be packed into the body at all, it has to be coiled up tightly, and it may be seen looking like a rather uneven coil of rope through the transparent abdominal wall. During the metamorphosis the animal does not feed, and when the frog-form is assumed the digestive tract is just half the length that it was before: the original small intestine has been formed anew as a shorter and wider tube, and while this is going on feeding is naturally impossible (cf. gnat, p. 131).

Enough has now been said to show that in the metamorphosis of the frog a complete series of changes takes place, whereby a fish-like animal becomes air-breathing and fitted for a life on land. All the organisms dealt with in this book exhibit in their life-histories a progression from a simpler to a more complex state, and in the gnat and the frog the later changes are apparent even to the superficial observer, for both of these forms hatch in a state widely distant from the adult condition which they reach by a complicated metamorphosis. No attempt has been made here to follow out the course of development before hatching, to trace the gradual elaboration of the cells and their progressive specialization to form the various organs and tissues, which can be done, indeed, only by somewhat complicated microscopical methods; but the starting-point of each animal in a fertilized ovum has been noted. The fertilized egg in these animals, like that of all other organisms, is a zygote, for it is formed by the union of two gametes, an ovum and a spermatozoon; so that, in its earliest being, the future frog or gnat is, strictly speaking, unicellular, with a structure as simple as that of any Protozoon. It will be remembered that the zygote of Vorticella, for example, undergoes rapid division as soon as it is formed. In the same way, the fertilized egg of the frog divides, but while the new vorticella-cells separate and lead independent lives, those arising by division of the frog's egg cohere (cf. Spirogyra, p. 46; Hydra, p. 70), so that a body of constantly increasing size and complexity is built up as they continue to be formed. Again, at a later, but still an early, stage, the embryo (cf. p. 70) consists of a two-layered sac, which, however different in different animals, still shows an outer protective covering with an inner nutritive lining, and herein recalls the adult

condition of Hydra or Obelia, just as the egg suggests Amoeba or Vorticella. From the time of hatching onwards, there is, however, a difference in the significance of the two life-histories The frog, as we have said, begins life as what is virtually a fish, and just as the ovum and the early embryonic form may be considered as reminiscent of a very far back ancestor, so may the tadpole be regarded as indicating that one not so remote was a fish-like animal. The gnat also begins life as an aquatic form, with a body something like that of a worm, but very unlike any worm that we know in many important respects, notably in its breathing apparatus, which is that of an insect from the beginning. Now very few insects pass through an aquatic phase; their whole structure, whether in youth or in adult life, is of an unmistakably terrestrial type; so we are forced to believe that the larva and pupa of the gnat do not represent ancestral stages in its race-history, but are simply new adaptations to the special needs of the particular form; just as the redia and cercaria stages of Distomum, or the spore-bearing generation of the higher plants (see p. 248) are adaptations to changed conditions of life. The tadpole, however, may be regarded as representative of a true ancestral form, and the changes which it undergoes in becoming a frog, equally with those which occur in the egg, as of race-significance. It is because of facts of observation as common as those of the frog's life-history, no less than of others more difficult to see and to interpret, of which numbers may be discovered in both Animal and Vegetable Kingdoms, that we believe that changes of this kind have taken place, and are taking place, in the race-histories of all living things; that we believe, in fact, in a doctrine of evolution.

CHAPTER XVII

THE PHYSIOLOGY OF THE RABBIT

(Lepus caniculus).

THE rabbit is one of the few mammals still found wild in Britain. Besides the wild ones many tame varieties are kept in this country, and among these there is considerable diversity of both form and colour. The wild rabbit is smaller than his domesticated brethren: the fur is of a brownish-grey colour shading almost to white on the lower surface, and the under side of the short conical tail is pure white. Wild rabbits live together in considerable numbers on heaths or commons, in the sandy soil of which they dig their burrows, a collection of burrows being known as a warren. They come out to feed or play, mostly in shady places, and their sombre colouring makes them very inconspicuous at the same time, as they run, the tail is stuck straight up, so that the white under side is plainly visible and serves both as a danger signal and as a guide to other members of the colony. If one rabbit be alarmed, he runs to his burrow with the white of his tail showing, so that all his companions are warned of an enemy and also given a lead away from danger. It is said that, when hard pressed by a foe, rabbits will take to water and swim some little distance to make good their escape. One of the most remarkable things about this animal is its extraordinary rate of multiplication. One pair has been known to have 260 descendants in a single year; there may be as many even as eight litters in a year and up to eight young ones in a litter. This great rate of increase has had most disastrous results in Australia, where the descendants of a few pairs taken over some years ago have proved a perfect curse. They are extremely destructive; entirely vegetarian, they do enormous damage to young crops of all kinds, and by gnawing the barks of trees cause these also serious injury. They seem not to be preyed upon by other animals and all attempts

to exterminate them have proved vain. In this country, owing to the presence of foxes, stoats, weasels, and birds of prey of various kinds, they are kept down to more reasonable limits, and they are also largely shot as ground-game.

Though relatively a small animal, the rabbit is large as compared with the frog. The head, which is large and of considerable depth, is set on to the body by a well-defined neck (Fig. 64), the body itself is bulky and raised off the ground by the legs, which are jointed as in the frog. The animal walks on its toes, so that it is raised not only by the leg but by nearly the whole length of the foot as well The integument, with its covering of hairs and the development of claws on the feet, contrasts with the unmodified skin of the frog, but its glandular nature is a feature common to both animals The hair occurs all over the body, covering the soles of the feet and even entering the mouth at the sides. Long stiff tactile hairs, called whiskers or vibrissae, are present on either side of the snout, and both upper and lower eyelids are fringed with lashes. Glands giving an oily secretion occur in connexion with the hairs, and there are others near the tail in which is formed a substance giving to the animal its peculiar smell. The mammary glands are specially developed in the female to furnish milk as food for the little ones until they are old enough to fend for themselves. From the sides of the head, just above the eyes, project long pointed 'ears' or pinnae (Fig. 64, *pn.*), which are erect and movable and serve to concentrate sounds. The nose again is movable, with the nostrils (*n*) at its tip, it is just above the mouth (*m*) which has hairy mobile lips, the upper being cleft, and showing the chisel-shaped front teeth within. The anus, which is terminal and lies beneath the tail, is quite unconnected with either excretory or reproductive ducts, which open just in front of it by a common pore.

The organs generally, like those of all mammals, show a great advance in structure and specialization, so that their several functions are more clearly defined than in any of the lower Vertebrata. It is for this reason, and also because this class has been most fully studied, that a sketch of Physiology is given in connexion with one of the Mammalia rather than with any of the forms

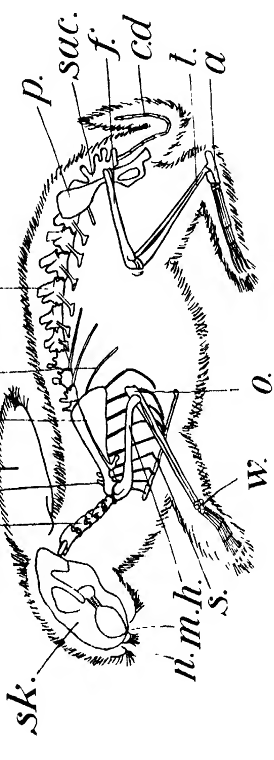


Fig 64. Outline of the body with the skeleton in position.

a. ankle	*n* nostril	*sac* sacrum
c. cervical vertebrae	*o* olecranon process of ulna	*sc.* scapula.
c d caudal vertebrae.	*p* pelvis	*sk* skull
f. femur.	*pn* pinna.	*t.* tibia.
h humerus.	*r* rib	*th* thoracic vertebra
l. lumbar vertebra.	*s* sternum.	*w.* wrist.
m mouth.		

already described. The skeleton, which, as will be remembered, gives support to the body and protection to its soft parts, is here less cartilaginous, more bony, and hence stronger, than in the dogfish or frog, with more resistant bones and firmer joints. In the skull practically all the cartilage is replaced by bone, and, as well as the symphysis of the lower jaws and the fusions of various cartilage bones, there is a third kind of immovable joint, the suture affecting chiefly the membrane bones and resulting from the interlocking of processes along their edges, which gives yet further firmness to the brain case. The sense capsules are bony and are closely fused to the cranium, and the hyoid apparatus is greatly reduced: part of it (as in the frog) supports the base of the tongue, part is pressed into the service of the auditory organ, and part is connected with the breathing apparatus.

The backbone is long and composed of about forty-five vertebrae The centra have flat faces and are separated by discs of cartilage in which the last traces of the notochord may be found (cf. dogfish) The vertebrae vary in general form according to the region to which they belong, and five such regions may be recognized the cervical or neck region (Fig. 64, *c.*) with seven vertebrae; the thoracic and lumbar (*th.*, *l*) with twenty, the sacrum (*sac.*) consisting of four fused vertebrae, and the caudal region, or tail, with about sixteen (*cd*) The thoracic vertebrae bear ribs (*r*), nine pairs of which are attached directly or indirectly to a jointed bony rod lying in the mid-ventral line and known as the sternum (*s*), thus a sort of casing of bone is provided for the anterior part of the body, in which lie the heart and the lungs, organs all-important to the life of the organism. Like the rest of the skeleton, the limb-girdles (shoulder and hip) and the bones of the limbs (*sc*, *o*, *h*, *w*, *p*, *f*, *t*, *a*) are strong and united by well-fitting joints, so that not only do they afford good attachment for the powerful limb-muscles, but they are also capable of executing vigorous movements when acted upon by the contractile tissue. It will be remembered that the chief property of muscular tissue is its power of contractility, or of becoming shorter, so that any other tissues to which its ends may be attached are drawn together, to be released again when reaction sets in and the muscle resumes its ordinary length; this property

is, moreover, possessed by the smallest units of such tissue, whether they be isolated and independent (contractile muscle-processes of Hydra), or massed together to form large bundles (muscle-segments of the dogfish or tadpole). In the higher animals, differences occur in the structure of the tissue as well as in its arrangement. As regards the structure, it may be said quite briefly that in one kind, known as striated muscle, the cellular structure has been lost, the cells having been modified to form fibres with a striped appearance, while the other, known as unstriated, retains its characteristic cells. With reference to the arrangement, we may note that the striated muscle, which since it is under the conscious control of its possessor is also called voluntary, forms bundles terminating in tendons which have bony attachments, and the unstriated muscles, also known as involuntary since they work automatically, constitute large sheets, or often tubes ('hollow muscles'), as the muscle coat of the digestive tract, to which reference will be made again later. The voluntary muscles form what is commonly known as 'flesh'. By their attachment to the skeleton, they not only cause the movements of the various parts, but also in their normal condition serve to keep the body in an upright position The animal might, for instance, in standing, balance on its four legs were the skeleton rigid, but the occurrence of joints makes it flexible, as may be seen in a dried skeleton, where, though all the parts are in their right positions and properly attached, the whole falls together in a heap unless held up by external aid. During life, the muscles give the support; they are so arranged that those of the two sides of the body, and of the different sides of the limbs, &c, act in opposition, and by the alternate drag, first on one side then on the other, prevent the joints from giving way, and the body from collapsing altogether: in a dead rabbit, where all the muscles are out of normal contraction, the body is quite incapable of supporting itself. There is no space here to consider the action of all classes of muscles upon their respective joints. one, may, however, be taken as an example. The biceps (Fig. 65 *b*.) is attached at one end to the extremity of the shoulder-blade (*sc.*) and at the other to the inner bone of the forearm just below the elbow (*o*). When it contracts

it becomes thicker and shorter and so the tendons at its ends are drawn closer together, and the forearm is pulled up towards the shoulder, as it would be when the rabbit is squatting. When relaxation sets in, the biceps resumes its former length and thickness, and by the contraction of the triceps muscle (*t*), which stretches from the shoulder-blade to the end of the elbow and acts in opposition to the biceps, the arm is restored to its original position. The elbow-joint, which is thus bent and again extended, gives a good illustration of a hinge-joint Every muscle, whether voluntary or involuntary, is under the control

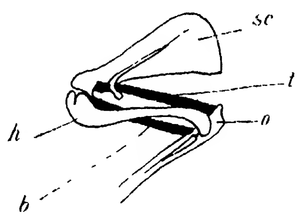


FIG 65 Diagram to show the working of the elbow-joint

b biceps muscle
h humerus
o elbow.
sc shoulder-blade
t triceps

of the nervous system · the voluntary muscles are supplied by branches from the ventral roots of the spinal nerves; for the involuntary there is also a special development known as the sympathetic system which, with the help of a branch of the tenth cranial nerve, innervates all the internal organs. Where voluntary muscles are concerned, the impulse to contract comes from the central nervous system, to which it has been transmitted by the sensory nerves in response to some stimulus received by the sense organs.

The elaboration of the skull and the strong build of the brain-case lead to the belief that the brain itself must be highly developed, and of more importance in the whole economy of the animal than is the case in the dogfish. The great advance is found in the cerebral hemispheres

(Fig. 66 *f.b.*) which attain to a very considerable size, and cover over the mid-brain almost entirely. This increase in the cerebrum is very characteristic of the Mammalia and reaches its highest point in man; it is associated with increasing intelligence and with a centralization of

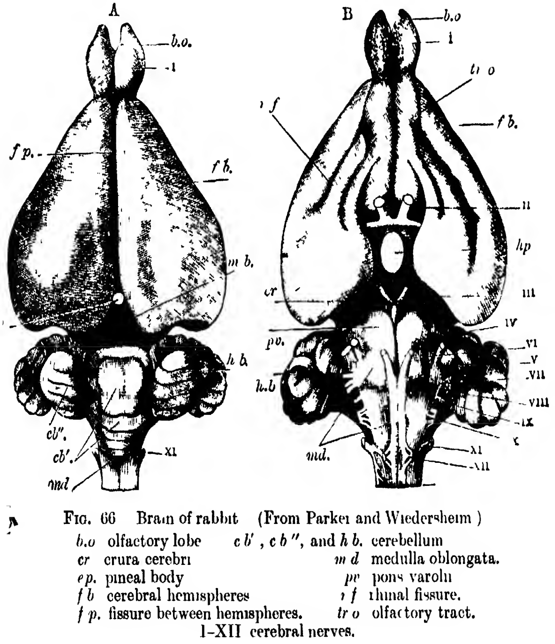


Fig. 66 Brain of rabbit (From Parker and Wiedersheim.)

b.o olfactory lobe		*c b'*, *c b''*, and *h b.*	cerebellum
cr crura cerebri		*m d*	medulla oblongata.
ep. pineal body		*pv*	pons varolii
f b cerebral hemispheres		*r f*	rhinal fissure.
f p. fissure between hemispheres.		*tr o*	olfactory tract.

I–XII cerebral nerves.

the control of the body in the brain, a condition which, indeed, is found only in the Vertebrates Careful experiment and observation have shown that the brain and spinal cord control all the activities of the body, but that the cerebrum makes the animal different from a self-regulating machine. While functions of all sorts are under the influence

of the other parts of the brain and of the spinal cord, the simpler actions by the cord, the more complex by the brain, all spontaneous movement, all 'feelings', whether of pleasure or pain as brought about by any of the living processes or by external stimuli, are controlled or appreciated by the cerebrum. To go one step further, the same statement holds true of ourselves, with the addition that self-consciousness, thought, intellectual faculty, all depend upon the great development of the cerebrum.

The part of the body-cavity enclosed by the casing of bone mentioned on p. 168, is known as the **thorax**; it is the anterior part of the coelom, of which the abdomen forms the posterior and larger half. The boundary between the two cavities may be felt on the outside by the edges of the ribs, it is furnished within by the diaphragm, a membrane strengthened by muscles and stretching right across the body from side to side and from vertebral column to sternum. The membrane is convex forwards, concave backwards, and the muscles are attached to the bones round the margin, converging towards the centre, where they end in a tendinous disc By the contraction of the muscles the thorax is enlarged at the expense of the abdominal cavity. The diaphragm is pierced for the passage of the oesophagus and the inferior vena cava.

The physiology of digestion has been indicated in the previous chapters, and its object is the same for all animals —to reduce the food to such a form as may readily be distributed to the tissues. The processes as carried on in the rabbit will now be given in detail, but first it is necessary to consider the structure of the digestive tract; its parts and their relations to each other are like those of the dogfish, but they are so much more complicated that they demand a full description. The mouth, which is at the tip of the snout (Fig 64, *m*), is bounded by furry lips of which the upper is cleft and provided with vibrissae (p. 166). The buccal cavity is large, and the jaws are beset with teeth of different shapes implanted in sockets. In front there are four chisel-shaped teeth called incisors, two in either premaxilla, arranged one behind the other. The posterior incisors are small, but those in front are very large and capable of unlimited growth, so that as the working face wears away the tooth is pushed down by the

formation of new material in the gum. The general nature of teeth has been explained (p. 146), so it is only necessary to say here that the enamel is confined to the front of these incisors, and as it is much harder than the rest of the

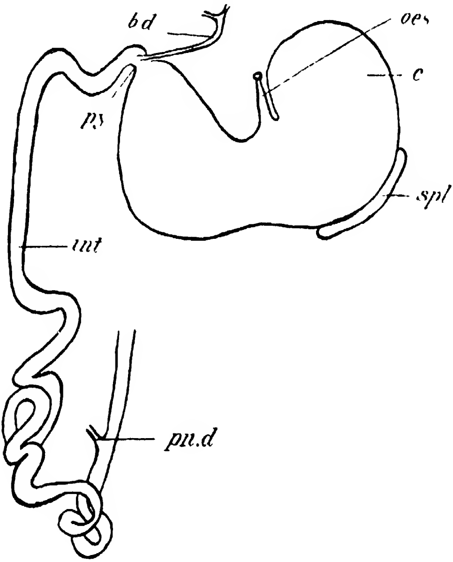


FIG. 67 Stomach and first part of the small intestine

b d bile duct
c cardiac end of stomach
int intestine
oes. oesophagus
pn d pancreatic duct
py. pylorus
spl spleen

tooth, wears less readily and gives an oblique gnawing face. The corresponding teeth in the lower jaw are only two in number, but essentially the same in character; they cut against the front upper pair Behind these teeth in both jaws comes a space, the diastema, covered with

an ingrowth of fur from without: then on either side of both upper and lower jaws is a group of teeth with wide grinding surfaces marked by ridges and grooves, these are the molars, of which there are six in the upper, five in the lower jaw, and, like the incisors, they continue to elongate as the grinding surfaces are worn away. Four pairs of salivary glands discharge a digestive secretion into the mouth. The roof of the mouth is partly bony, partly soft; the membrane covering the bony part is thrown into folds so as to form hard ridges, and behind, it makes a sort of curtain to divide the pharynx into a buccal and a nasal portion; from the buccal portion open both the oesophagus and the windpipe or trachea. The oesophagus (Fig. 67, *oe.*) is a narrow muscular tube running through the diaphragm to open into the stomach (*c.*, *py.*) which is a wide curved sac with a larger cardiac, and a narrower pyloric end, the lining being beset with numerous glands in both cardiac and pyloric portions. along its outer curve lies the long red spleen (*spl.*). Beyond the stomach is the small intestine (*int.*), in the first loop of which lies the pancreas, with its duct (*pn.d.*) opening into the further bend of the loop. The liver, a massive gland composed of five lobes fitting into the concavity of the diaphragm and overlying the stomach, carries the gall-bladder on its under surface and discharges its secretion by means of the bile duct (*b.d.*) which enters the intestine close to the pylorus. The small intestine attains a length of seven or eight feet, a great elongation which is to be expected from the vegetarian habit of the animal (cf. p. 154). It is narrow and much convoluted, and its walls lodge digestive glands and also exhibit tiny projections of the lining membrane called villi, which have something the appearance of the pile of velvet. The intestine terminates in a rounded chamber, the sacculus rotundus, from which are given off the large intestine, and the caecum, a wide tube some inches long, which ends blindly in the narrow vermiform appendix. The rectum opens straight to the exterior by the anus, for there is no cloaca.

The musculature of the digestive tract consists of a tubular coat of unstriated muscle-cells (p. 169). The coat is composed of two layers, one with a longitudinal disposition of the cells, the other with a circular arrangement.

The muscles of the whole canal do not act at once; the contraction, as also the relaxation, is rhythmical, so that while one part of the tube is narrowed the next is dilated, and so on. The waves of movement are always from the stomach to the anus, and so in whatever part of the canal a given mass of food may be, it is necessarily forced towards the hinder end of the body. The digestive tract is innervated from the sympathetic system, and also by branches of the tenth cranial nerve (p 170), but its movements are purely involuntary, and entirely outside the conscious control of the rabbit

During its passage through the alimentary canal the food taken in by the mouth has all its nutritive parts dissolved, so as to be absorbed ultimately into the blood, while valueless material is got rid of. The solution of the food is accomplished chiefly by the agency of ferments, such as we have met with before in both plants and animals (p. 12, &c) In the mouth food is broken up by the teeth and moistened by the secretion of the salivary glands, which contains a ferment (ptyalin) for turning starch into sugar. The food passes down the oesophagus to the stomach, where the muscular contractions of the coat of this organ keep fresh portions exposed to the action of the secretion of the gastric glands. The principal effect of this secretion is to dissolve proteins, for the ferment present (pepsin) acts upon these substances. There is free hydrochloric acid in the stomach during digestion, also secreted by the glands, for pepsin is active only in an acid solution. By the breaking-down of protein matter, fat is set free from the cells in which it occurs, and by the warmth of the body some of it is liquefied. On reaching the intestine, the liquid contents of the stomach are at once met by the bile, which is poured down from the gall-bladder. This secretion neutralizes the acid of the gastric glands, and so prepares the food for the action of other ferments, it also renders the fat easy of absorption by the walls of the intestine. A little further along, the intestine receives the secretion of the pancreas: this contains ferments (amylopsin, trypsin, steapsin) which act upon all classes of food-stuffs, turning into sugar the starch which has escaped the action of the saliva, dissolving undissolved proteins, and emulsifying

fats. The glands of the small intestine itself secrete a liquid which contains ferments for the solution of both proteins and starch, but its most important property is its power of increasing the activity of the pancreatic secretion. So much for the digestive processes: absorption takes place step by step with digestion, and results in the transference of the digested food from the alimentary canal to the vascular system. In the small intestine the villi upon the walls contain each a lymphatic vessel, known as a lacteal, and also a capillary network. Food passes through the wall of the villus into both sets of vessels, and ultimately, by whichever course, reaches one of the great venous trunks of the body.

The circulation of the rabbit is far more complicated than that of the lower Vertebrates, for the heart is completely divided longitudinally into venous and arterial sides. In the heart of the dogfish there is only venous blood in that of the adult frog, venous and arterial blood mix, but in the rabbit there is, as it were, a double heart, for after birth there is a complete separation of right auricle and ventricle from left auricle and ventricle, and hence a separation also of venous from arterial blood. Then the truncus arteriosus is much reduced and the sinus venosus is present only as a tiny cavity, the coronary sinus, which receives blood from the veins draining the substance of the heart, and empties into the right auricle. The heart is enclosed in the pericardium, a two-layered sac situated in the thorax, a little to the left of the middle line: the right side is the larger, but the left is the more muscular. The muscles form sheets around the heart, consisting of a sort of network which is far more compact for the ventricles than for the auricles. The sheets are, like all 'hollow' muscles, composed of cells, but the cells in this case show the striation characteristic of voluntary muscles. The heart muscles are undoubtedly involuntary, but they have a great work to do in pumping blood all over the body, and hence must be stronger than those, for instance, of the alimentary canal. Most of the muscles of the body require a period of rest after prolonged activity; those of the heart can rest only in the momentary pauses between the heart-beats. Auricle and ventricle of the same side communicate

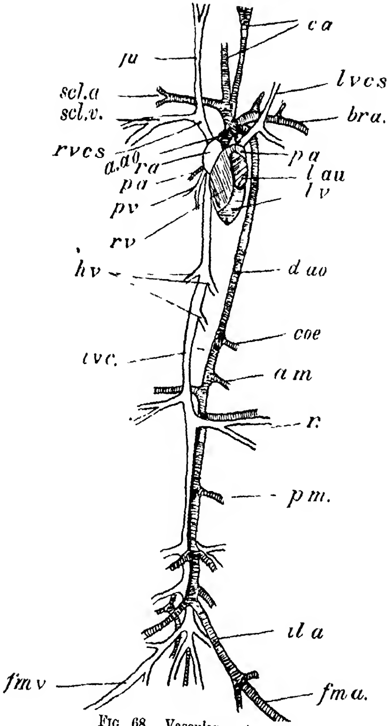


FIG 68 Vascular system.

a.ao. arch of aorta.
a.m. anterior mesenteric artery.
br. a brachial artery.
c. a carotid artery.
coe. coeliac artery.
d ao. dorsal aorta
fm.a. femoral artery
fm.v. femoral vein
h.v. hepatic veins.
il.a. iliac artery.
i.v.c. inferior vena cava.

ju jugular vein
l.v left ventricle.
p a pulmonary artery
p.m posterior mesenteric artery.
p v pulmonary vein
r renal artery and vein
r.au right auricle.
r.v. right ventricle
r v c.s right superior vena cava.
scl.a. right subclavian artery.
scl.v. right subclavian vein.

by an aperture guarded by valves, that on the right side consisting of three membranous flaps and called the tricuspid; that on the left, of two flaps and called the mitral valve. Both ventricles are very muscular, and the flaps of the valves are attached by tendinous cords to muscular projections of the ventricular walls in such a way that, while they lie flat and allow of the passage of blood from the auricle when the ventricle is empty, when it is full they rise up and close the aperture, so that there can be no back-rush to the auricle. The veins opening into the right auricle (Fig. 68, *r.a.*) are the venae cavae (*r.v.c.s*, *i.v.c*), a right and a left superior and a single inferior, and their apertures are guarded by valves The right ventricle (*r.v.*) is emptied by the pulmonary artery, which takes venous blood to the lungs to be arterialized. Into the left auricle (*l au.*) opens the pulmonary vein (*p.v*), returning arterialized blood from the lung, and from the left ventricle (*l v*) arises the aorta, a stout muscular trunk, again with valves at its origin. The superior venae cavae return blood brought from the head and shoulders by the jugular and subclavian veins (*ju.*, *scl v.*), and the inferior vena cava receives blood from the hinder part of the body All the veins are furnished with valves to prevent a back-rush of blood towards the capillaries. The aorta (*d.ao.*) is the one trunk by which arterial blood leaves the heart. it bends back above the heart, passes over to the left side, and runs backwards in the abdomen, close to the backbone. At the bend it gives off the carotid (*ca*) and subclavian (*scl.a.*) arteries: the carotids and the right subclavian are united for a short distance, leaving the aorta by a common stem. The first part of the aorta, i e. from its origin until after it has given off the carotids, with the root of the pulmonary arteries (Fig. 70, *b.* and *c.*), may be regarded as corresponding to the truncus arteriosus, but evidently only the left half of the second arch of the dogfish, or the left systemic of the frog, is represented Of the vessels arising from the dorsal aorta, we may note the hepatic artery supplying the liver, and the coeliac and mesenterics (Fig. 68, *coe.*, *a.m*, *p.m.*) serving the digestive tract. Blood is returned from the digestive tract by the portal vein which breaks up in the liver, the capillaries uniting to form the hepatic vein, which

discharges into the inferior vena cava. There is no renal portal system

The blood travelling by the portal vein is laden with the products of digestion obtained from the capillaries in the walls of the stomach and intestines. In the liver this blood is deprived of much of its sugar (which is stored in the liver-cells), and with the blood from the hepatic artery furnishes the constituents of bile The impoverished blood travels by the hepatic vein to the inferior vena cava and thence to the right auricle, where it meets with the contents of the superior venae cavae, and passes with that to the right ventricle, and so by the pulmonary artery to the lungs. In the lungs, the venous blood becomes arterial, and is returned to the left auricle, from which it passes to the left ventricle to be pumped into the aorta, and so all over the body The whole of the journey of the blood from the heart and back again is known as the circulation, and was, in its complete form, the discovery of the great Physiologist, William Harvey, who lived in the seventeenth century.

Like the veins, the vessels of the lymphatic system are provided with valves, so arranged that the flow shall be towards a longitudinal trunk, the thoracic duct, into which the smaller vessels empty, and itself discharging into the left superior vena cava The vessels are beset with frequent lymphatic glands

The alternate contraction and expansion of the heart causes what we know as its 'beat', and also the pulse which may be felt in any artery The heart is a muscular tube which dilates to become filled with blood and contracts to force it on into the arteries The arteries are elastic tubes and are distended by the force of the rush of blood from the heart, when their elasticity comes into play they shrink to their former size For instance, when the left ventricle contracts, it forces its contents into the first part of the aorta, and then dilates to receive another supply of blood from the auricle this distension and filling jerks the heart against the ribs and gives the 'beat'. When the first part of the aorta becomes constricted its blood is squeezed on to the next region and dilates that, while the first part is again expanded by a new supply from the ventricle As each new portion of blood

is received, the last is forced on so that a rhythmical contraction passes along the aorta, or indeed any large artery, and the blood moves in an intermittent and not a continuous stream. This is well seen when an artery is cut, for the blood escapes from the end nearest the heart in jerks. It is the wave of contraction which is felt as the 'pulse', the 'beat' in the artery coming after the 'beat' in the heart, at an interval corresponding to the distance of the artery from the heart. The greater the distance from the heart, however, the feebler the pulse, for naturally the wave started by the ventricle tends to die away as it moves on Before the blood reaches the veins it has to traverse the capillary systems. Now each capillary is a very minute tube, it may, indeed, be no wider than a single blood-corpuscle , but these vessels are so numerous that their total capacity greatly exceeds that of the arteries ; hence, there is no distension of their walls by the incoming blood, and the flow is much slower than in the arteries, owing not only to the greater capacity, but also to the greater friction caused by the large extent of the total capillary wall The loss of speed allows of a transudation of blood through the delicate walls (p. 150); and the great resistance offered by the capillaries causes the stream to lose its jerky character and to maintain a regular progress : the pulse is therefore lost in the capillaries, and is not regained even when the veins, with their smaller total capacity, are reached. The valves occurring in various parts of the vascular system ensure that the blood shall flow always in the same direction

It will have been noticed that, as well as a double heart, there is really a double circulation the journey of the blood from the right ventricle to the lungs and back to the left auricle is sometimes called the lesser, that from the left ventricle to the body generally and back to the right auricle, the greater circulation.

As well as taking food and oxygen to all the tissues, the blood is the great regulator of heat. The rabbit, like all other animals with a covering of fur or feathers, is warm-blooded, i.e its body remains, during health, at a constant temperature irrespective of the condition of heat or cold of the surroundings the frog and the fish, on the other hand, are cold-blooded, the body in

their case varying in temperature with the air or water in which it lives. The warm-blooded condition depends on the more rapid oxidation which goes on in the body (p. 6), and all warm-blooded animals display not only a complete separation of arterial from venous blood, but have the arterial blood returned to the heart before going to the body, so that a fresh pumping sends it out with increased vigour The blood, circulating freely all over the body, can get rid of superfluous heat when it comes in contact with the outside air (or water) and this cooling-down process takes place from the lungs and the skin, both of which present really external surfaces The regulation of heat is under the direct control of the nervous system, special nerves determining the calibre of the surface vessels, and thus the quantity of blood which they shall carry, consequently the amount of heat which shall be given off[1] The fur acts as a non-conductor, and prevents the too rapid radiation of heat in general it is thicker in winter than in summer

The arrangements for the oxidation of the blood must be considered now. Air is taken into the body through the nostrils and passes through the nasal cavity into the pharynx. The windpipe opens by a slit-like orifice, the glottis, and is provided with a sort of cover, the epiglottis, to close it over when food is going down the oesophagus (p. 174); for the food-path crosses the wind-path, and were things to go the wrong way much discomfort must ensue. The walls of the upper part of the wind-pipe, the larynx, are supported by pieces of cartilage derived from the lost visceral arches (p. 136), and a series of rings, imperfect above where the oesophagus lies, strengthen the hinder region, or trachea. Upon the ventral face may be seen the thyroid gland, a large bilobed mass. Its function is not understood, but its removal or disease causes such changes in the animal as to lead to the belief that its secretion contains some substance absolutely necessary to the well-being of the body. Where neck

[1] In many animals (e g ourselves), the skin is beset with numerous 'sweat glands', which afford another means for regulating heat Their watery secretion not only loses heat by radiation, but is also a source of great loss to the body by evaporation and consequent lowering of temperature

and thorax meet the trachea divides to form a right and a left bronchus; each of these divides again and again, the ultimate divisions, very tiny tubes called bronchioles, dilating at the end to form air-vesicles or alveoli. These alveoli, with the bronchioles, make up the main mass of the lung, which is thus extremely spongy; it is also very vascular, for the capillaries resulting from the breaking up of the pulmonary artery run freely throughout the whole of its substance. The lungs lie one on either side in the thorax, and are covered by a double membrane, an outer and an inner pleura. The inner pleurae are closely adherent to the surface of the lungs, and the outer to the body-wall. The gaseous exchange is effected as follows:—the thoracic cavity is made larger in two ways: the diagram contracts, becomes flattened, and increases the cavity backwards (p. 172), the outer muscles of the ribs contract and drag them forwards and outwards, so that the thorax is made larger in circumference also, and the pressure within is less than that without then air rushes in through the nostrils (and mouth) to equalize the pressure (inspiration). Now the inner muscles of the thorax contract, the outer ones relax, and the diaphragm moves forwards, so that the thoracic cavity returns to its original size; at the same time the elasticity of the lungs comes into play and they collapse. thus air is expelled (expiration). Oxygen brought in with the inspired air comes into close contact with the capillaries in the lungs, and an exchange between the blood and the air takes place, the former losing carbon dioxide to, and receiving oxygen from, the latter.

The excretory function is discharged by the kidneys, compact reddish-brown masses of a characteristic form attached to the dorsal body-wall, one on either side of the backbone. From the inner concave side of each organ, a ureter runs back to open into a distensible reservoir, the bladder. There is no cloaca, and all connexion between rectum and excretory and reproductive ducts is lost, there is, however, a common duct for excretory and reproductive products, called the urinogenital canal. As in the dogfish, the kidney is made up of numerous tubules, ending in capsules which contain each a glomerulus, or tuft of blood capillaries. The tubules constitute a com-

pact mass, which forms the bulk of the organ and terminates in a projection called the pyramid on the concave side. The ureter leaves the kidney as a wide sort of funnel and the pyramid projects into the cavity of this. The tubules of which the substance of the gland is composed discharge their secretion by a few wider tubes or collecting

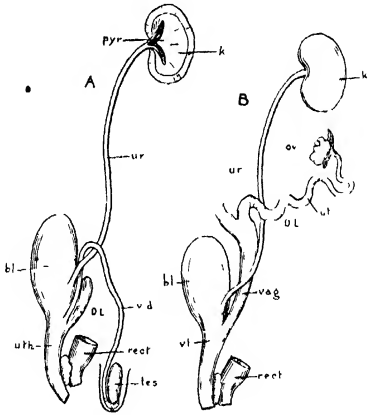


FIG 69 Diagram of excretory and reproductive systems A of a male, B of a female In A the kidney has been split horizontally

bl	bladder	*rect*	rectum	*uth*	urethra
k	kidney.	*tes*	testis	*vag*	vagina
ov	ovary	*ur*	ureter.	*vt*	vestibule
pyr	pyramid.	*ut*	uterus	*v d*	vas deferens

ducts, on the apex of the pyramid Branches of the renal artery, which enters the concave side, break up in the substance of the gland to form capillary tufts which give the glomeruli. From the blood in the capillaries nitrogenous waste dissolved in water is removed by the cells of the kidney tubules, and passes down the cavity to be poured into the ureter from the pyramid, and thus to reach the exterior. The blood, relieved of the waste material, is returned to the inferior vena cava by the

renal veins. The function of the kidney is identical with that of the nephridium of Lumbricus, or the contractile vacuole of Vorticella.

The ovaries (Fig. 69 B, *ov.*), two in number, lie one on either side some little way behind the kidneys of the female. They have an uneven appearance, owing to the protrusion of the sacs containing the ova. The oviducts have each a wide funnel-like opening at the free end. that the ovum, when extruded, shall fall into the oviduct is ensured by the movement of the opening towards the ovary which is practically grasped by the funnel. The part of the duct next to the funnèl is narrow and somewhat coiled. It dilates farther back to form a chamber, the uterus (*ut.*), for the retention of the egg during its development: this opens side by side with its fellow into a single wide cavity, the vagina (*vag.*) which leads into the urinogenital canal, or vestibule, as it is called in the female (*vt.*). The testes are not included in the body, but come to lie in saccular outpushings of the coelom on the outside, close to the opening of the urethra (Fig 69 A, *uth*), by which name the urinogenital canal is known in the male. The vasa deferentia pass upwards from these sacs and open into the urethra near its origin. The urethra is prolonged into an organ to effect the transference of the spermatozoa to the vagina.

The embryo rabbit is retained within the body of the mother until it has attained a form closely approximating to that of the adult, and thus its development presents a study of greater difficulty than can be undertaken now, but in view of what was said in the last chapter as to the significance of life-histories, and the support which they are apt to afford to the theory of evolution, it is interesting to note that the rabbit gives no exception to the general rule. It starts in life as a zygote, passes through a phase when it possesses a two-layered body, and later, while still closely enfolded in the maternal tissues, presents such essentially fish-like characters as clearly marked gill-clefts (not, of course, functional) with the special nerve and vascular supply (Fig 70), which are familiar in the dogfish or tadpole; while the vertebral column again is preceded by a notochord. From this point onwards the development is a gradual adaptation to the needs of a terrestrial life, and

may be compared, allowing for difference of environment, with what takes place in the tadpole The only conclusion

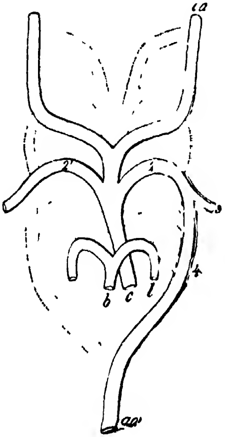


FIG 70 Diagram of the arterial arches of a mammal Those which persist in the adult are outlined in black, those which disappear are dotted. (After Boes)

ao aorta
ca carotid artery
b. pulmonary trunk
l pulmonary artery
c. aortic trunk.
s left subclavian artery.
1–4. primitive branchial arches

to be drawn from these facts is that the rabbit, like the frog, is descended from some fish-like ancestor, and that in its development is indicated its race-history

CHAPTER XVIII

THE MOSS PLANT (*Funaria hygrometrica*) AND ITS ALLIES

WE turn now from the study of animals to that of plants, which will occupy the remaining chapters of the book. The moss plant is unlike Spirogyra and Sphaerella, the only green plants so far described, in showing very marked differentiation of parts and in being adapted for life on land, two characteristics which are probably not unconnected, as will be pointed out later, when the functions of the different parts of the plant are described.

A moss plant consists of parts at first sight essentially similar to those familiar to every one in the flowering plants; slender rhizoids penetrate the superficial layers of the material on which it grows, while an erect stem bears delicate flat green leaves up to the light.

Each rhizoid, when examined under the microscope, is found to consist of a simple chain of cells, set end to end after the manner of the cells in a filament of Spirogyra. They have delicate cell-walls and abundant finely granular protoplasm, but are destitute of chlorophyll. Unlike the rhizoids, the stem is thick and solid, and made up of many layers of cells. It can, indeed, only be satisfactorily studied by the help of sections. These reveal that all the cells in the stem are not alike, three different kinds being distinguishable. The outside layer is composed of cells whose walls have become thickened and hardened at the expense of the living substance, which has often quite disappeared Sometimes even two or three layers become modified in the same way. The cells of the next few layers are many-sided, about equal in all dimensions, are still living and have thin walls, they are called parenchymatous When young, before the walls of the outer layers have become much thickened, they contain chloroplasts. In the middle of the stem are long, narrow, thin-walled cells closely packed together, while a strand

of the same kind of tissue runs up the middle of each leaf, forming a mid-rib which can easily be distinguished by the naked eye. Each of these strands penetrates from the leaf a little way into the stem, but there is no direct communication between similar cells of stem and leaf. The rest of the somewhat oval leaf is merely a single layer of thin-walled living cells containing chloroplasts, which

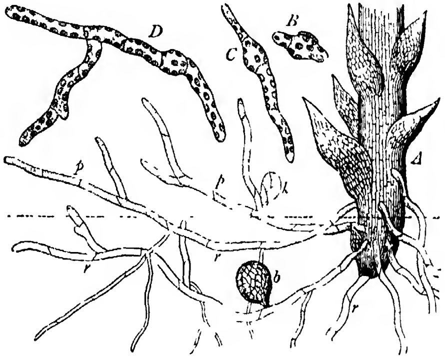


FIG. 71. A. Lower part of a moss plant bearing leaves and rhizoids. (After Luerssen, from Scott.)

b underground bud
k bud from which a new leafy stem will grow
p secondary protonema
r rhizoids which grow up above ground

B, C, D Developing protonema

give a vivid green colour to the whole. In all parts of the plant, growth is purely apical new branches are formed by division at the actively growing young tips of the rhizoids, and new leaves arise at the growing-point of the stem. The latter consists of a single cell, shaped like a three-sided pyramid and set with its apex pointing into the stem and its base upwards. Division never takes place parallel to the base, but segments are cut off each of the other sides in succession, each segment then dividing into an inner and an outer half, the inner goes to hold up the stem, while the outer divides again into

an upper and a lower half. The upper cell gives rise to the leaf, which grows in length by means of a two-sided apical cell, while the lower may give rise to a bud which will grow out into a new branch of the leaf-bearing stem. The fact that a leaf is formed from every segment cut off the apical cell of the stem accounts for the crowding of the leaves, as well as for their arrangement in three vertical lines on the stem, while no two leaves are at the same level.

The method of nutrition of the moss plant is essentially similar to that of Spirogyra. A difference arises, however, from the fact that, while Spirogyra is bathed at all points by the water from which all its nourishment is drawn, the moss must obtain its solution of nitrogenous food material from the solid ground, rock, or wall to which it clings, while a large green surface must be exposed to the air and light for the exchange of gases and the assimilation of carbon dioxide and water. These two fundamental needs are supplied on the one hand by the delicate branched rhizoids, with their thin walls and large absorbing surface, and, on the other, by the flattened green leaves, whose cells also have thin walls through which the gases of the atmosphere can readily diffuse. The leaves, therefore, become naturally special organs for respiration as well as for the intake of carbon dioxide, though probably the whole surface of the plant respires to a certain extent The exposure of these delicate walls to the atmosphere has still another result. Cellulose, like many other organic substances, has a great power of imbibing moisture. If the air be very damp, moisture will be absorbed by these walls from the atmosphere, but more often they obtain from the fluids within the cell their water of imbibition, which, at the exposed surface, passes away into the air, its place being supplied again from the moisture within the cell. Thus there is most often a continual passage of water vapour from within the cell outwards through the cellulose walls, and the leaf is said to transpire. This process necessarily takes place wherever unaltered cellulose walls are exposed to the air and will often be referred to again. Transpiration, which, if excessive, may lead to the drying up and

finally even to the death of the plant, is of great importance if atmospheric conditions are favourable, so that water is not carried away faster than it can be taken in by the rhizoids. In a multicellular body like that of the moss plant, food material not only enters the rhizoids by the process of osmosis (p 9), but it must be distributed from cell to cell throughout the body by the same means. As the force and direction of the osmotic current depend on the relative degree of concentration of the two solutions concerned (see p. 10), it is obvious that a greater concentration of the cell sap is necessary at the top of the plant than at the bottom, in order to secure an upward osmotic current, and such a concentration is provided for by the process of transpiration If this is not excessive, therefore, it results in an increased flow of food material towards the leaves. The function of the leaf is thus mainly threefold —(1) exchange of gases, as in respiration and the absorption of carbon dioxide with the return of oxygen, (2) the assimilation of carbon dioxide and water by the chloroplastids in the presence of light, (3) transpiration, which, under certain circumstances, may give place to absorption of moisture from the atmosphere.

The function of the stem is primarily to hold the leaves up to the air and light, and to act as a connecting link between the rhizoids and the leaves Food material seems to pass up through the long cells of the axial cylinder, the tissue of which is thus often called conducting tissue The purpose of the elongated form of cell, with the consequent reduction in the number of cell-walls is obvious The outermost layer of cells of the stem is specialized to give rigidity to the whole, while the parenchymatous tissue, when young, apparently helps the leaves in their work of assimilation.

The superficial resemblance to the higher plants in the general form of the body has already been pointed out. It cannot be shown yet why the rhizoids and leaves of the moss cannot be regarded as representing the roots and leaves of higher plants, but in both some part must penetrate the soil to absorb food, and some part spread above ground for the procuring of light and the interchange of gases, and here really the resemblance ceases.

At certain times of the year the leaves at the upper end of the plant may be seen to be spread apart to form a little shallow cup coloured red in the centre. A number of these cups together form quite a vivid patch of colour, and they are often called the 'flowers' of the moss. The resemblance to the flowering plants here too, however, is

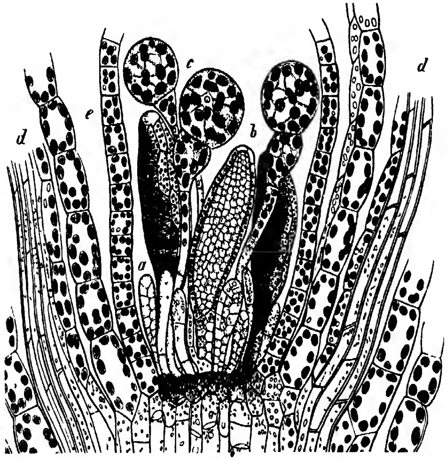


FIG 72. Longitudinal section through a shoot of *Funaria hygrometrica* bearing antheridia (After Goebel)

a. young antheridium
b almost mature antheridium
c. paraphyses
d. leaves divided through the middle
e leaves divided through the lamina

quite superficial In the centre of the cup, amongst certain hair-like processes called paraphyses, are little oval masses of cells, the antheridia. Each is originally derived from a single cell, but, as growth and division take place, it becomes differentiated into an outer wall and an inner mass of cells, which finally become spermatozoids. On the rupture of the wall the inner mass is pushed out at once and the spermatozoids are set free.

Each is provided with two cilia, which are obviously of no use except in the presence of water, and they are powerless unless at least a thin film of water, in which they can swim, covers the surrounding leaves

On stalks lower than those which bear the antheridia are other somewhat similar cup-shaped structures, less conspicuous because smaller and not brightly coloured Here, among the leaves, are little bodies known as archegonia. Each, when full grown, is somewhat flask-shaped, with a swollen basal portion, or venter, and a long neck Of the inner cells one large one at the base forms the ovum, while those above, filling the neck, are known as the canal cells These, when the ovum is ripe, disintegrate, swell up, and push apart the cells forming the neck. Probably this always happens in the presence of water, in which case there will most likely be other drops trickling from the red cups above, and these may carry spermatozoids with them If so, attracted apparently by the presence of cane sugar in the disintegrated canal cells, some will wriggle down the neck of the archegonium and one will fuse with the ovum

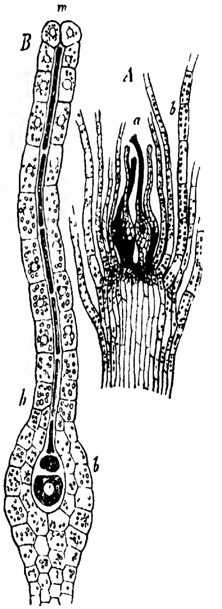


FIG 73

A Longitudinal section through a shoot of *Funaria hygrometrica* bearing archegonia (After Goebel)
a archegonia
b leaves

B A single archegonium
b venter with ovum
h neck
m orifice, still closed

The cell resulting from this fertilization, known in mosses as an oospore, is, of course, comparable with the zygote of Spirogyra or Mucor, or the fertilized egg-cell of Hydra, and though in this case it never becomes detached from

the parent plant which gave rise to the megagamete, the results of its growth must be looked upon as, in a real sense, a new plant.

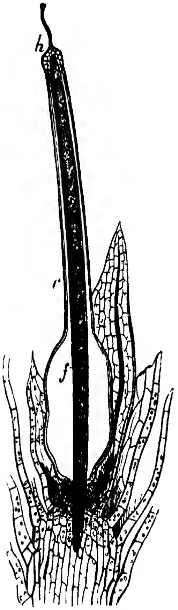


FIG 74 Longitudinal section showing the development of the sporophyte (After Goebel) *c* venter of archegonium forming the calyptra *f* developing sporophyte *h* neck of archegonium

Immediately after fertilization the oospore surrounds itself with a cell-wall. It does not, however, enter upon a long resting stage; division proceeds and a little rod of cells is rapidly formed in the archegonium. An apical cell is present at each end, and for a time growth takes place not only upwards but also downwards into the tissues of the parent, forming a structure known as the foot At first the archegonium keeps pace with the growing embryo within it by growing itself at the apex. Presently, however, a split takes place round the venter, the upper half of which, together with the neck, is carried up on the rapidly elongating stem formed by the young embryo. This stem becomes swollen at the top and forms what is often called the fruit, but is, in reality, the sporangium of the new moss plant

The sporangium itself is made up of two parts, a thickened solid lower part and an upper part which eventually becomes hollow and is specialized for the production of spores. The cells of the lower part contain chlorophyll, and evidently to a certain extent their functions are identical with those of the leaves on the parent plant. The exchange of gases and the giving out of water vapour are, however, hindered by the outer walls of the external layer of cells, which are thickened for the sake of firmness The difficulty which would thus arise is got over by the presence

of tiny openings, or stomata, which lead into spaces between the cells. The walls surrounding the inner cavity of course have no need of thickening, and are therefore thin and delicate, so that moisture and dissolved gases can easily pass through them. Each stoma is surrounded by two

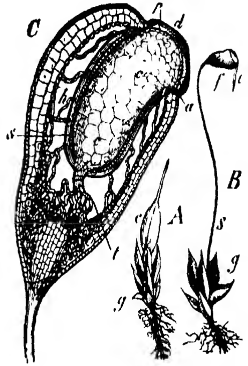


FIG. 75 *Funaria hygrometrica* (After Goebel)

A Young leafy stem.
  c calyptra — *g* stem
B Plant with almost mature sporophyte
  c calyptra. — *g* gametophyte
  f capsule — *s* stalk of capsule
C Longitudinal section through the capsule
  a ring where lid will be separated. — *h* air space
  c columella — *p* peristomial teeth
  d lid. — *s* layer where spores are being formed

sausage-shaped guard-cells, which regulate the size of the opening, for in damp weather they readily absorb moisture, and so become thick and narrow, pulling apart from each other, while in dry weather they collapse so that their inner edges almost meet. The dangers of excessive transpiration are greatly reduced by this arrangement, for on a dry day the stomata will close, the air in the intercellular spaces will rapidly become saturated, and, as fresh

dry air is not admitted, transpiration will nearly cease. The guard-cells are also sensitive to different degrees of illumination, so that the stomata open in light and allow a free passage to carbon dioxide. The two guard-cells are not always easily seen, as in Funaria the dividing walls between them sometimes disappear, and it looks as though the opening were surrounded by a single ring-shaped cell.

The upper part of the capsule, or sporangium proper, becomes very complicated in structure when ripe, chiefly owing to elaborate contrivances to ensure that the spores shall be shed under suitable conditions. In a fairly young capsule there is a central mass of tissue separated from the outer wall by a space (Fig. 75, *h*), which is, however, crossed here and there by chains of cells Near the outside of the inner mass a layer of cells becomes differentiated for the formation of spores (*s*), and the inner sterile part is now known as the columella. This widens out at the top to form a group of cells at the apex of the capsule. A small circular patch in the outer layer of these becomes specialized as a lid (*d*), round about which is a ring of cells with thin walls altered in such a manner that they easily decay (*a*) When the spores are ripe the columella shrivels up, and the whole cavity thus formed becomes filled with a dense mass of spores The remains of the old archegonium, which till now has stayed as a cap on the top of the sporangium forming the calyptra, is blown away, and the lid drops off. The spores are still protected, however, by another layer of cells (Fig 75, *p*), or rather a double layer of walls, for the contents have completely disappeared, and, owing to unequal thickening, the transverse partitions have given way, leaving the strong upper and under walls as two distinct layers As the result of a further elaboration of unequal thickening, both layers become torn into wedge-shaped strips, united by their broad bases round the rim, but with free apices pointing inwards. The opening is thus guarded by a formidable double layer of teeth, which regulate the dispersal of the spores, for in wet weather the thickened walls swell up and completely close the opening, while in dry weather they shrink and allow the spores to pass between them.

It has already been pointed out that the sporangium, with its stalk and foot, must, strictly speaking, be regarded as a different individual from the plant of which apparently it forms a part. As it gives rise to spores it is known as the sporophyte, and is thereby distinguished from the leafy moss plant which, as it gives rise to gametes, is known as the gametophyte. The sporophyte is partly parasitic on the gametophyte, obtaining, through the tissues of the foot, sap containing nitrogenous material from the tissues of the parent. It appears, however, that it is able to obtain carbon dioxide and manufacture sufficient carbohydrate material for its own use.

Each spore contains reserve food material and chlorophyll, in this latter respect differing from the majority of spores. If suitable conditions are found the outer wall is soon broken, and the spore gives rise to a chain of cells separated by oblique transverse walls. The chain grows, branches, and forms a network which somewhat recalls that of Mucor, except that it contains chlorophyll. Here it is known as the protonema. After a time buds occur here and there on the thread (Fig. 71, *k*), grow upwards, and become differentiated into stem and leaf, while certain of the threads penetrate downwards, lose their chlorophyll, and become rhizoids.

The life-history may be represented in a table as follows, where the double stroke shows the origin of a new generation:—

Moss-plant (Gametophyte.)
/ \\
Antheridium Archegonium
| |
Spermatozoid — || — Ovum
||
Oospore (Sporophyte.)
|
Stalked Sporangium
||
Spores (Gametophyte.)
|
Protonema.

The moss resembles Mucor in its two kinds of reproductive processes. In this case, however, the two processes cannot be accomplished by one individual, whereas in Mucor the

same mycelium may give rise now to spores, now to gametes. Again, in the moss, spore and fertilized egg-cell give rise to two quite different structures, so that there are really two moss plants totally unlike each other, yet they appear to be the same individual though in reality one is the offspring of the other It is certainly a complication of the problem of heredity that a reproductive cell should have the power to grow into the likeness, not of its parent, but of its grandparent, an individual more widely different from its parent than a sycamore is from an oak. A similar alternation of individuals characterized by different modes of reproduction has been described for Distomum (p. 104). While rare in animals, it is extremely common in plants and will be traced in higher forms.

The mosses form a large and widespread group. They are all adapted to life on land and have a well differentiated gametophyte. The adaptation to land conditions is, however, incomplete, owing to the nature of the gametes, which makes the process of fertilization impossible except with the help of water. It is perhaps for this reason that the mosses, whose most highly differentiated and independent generation is the gametophyte, never attain to any very considerable size, so that, though they are extraordinarily numerous, they often escape observation altogether, on account of their insignificance. Naturally they grow most luxuriantly in damp and shady places, but they are also frequently found forming soft green cushions on the bare surface of rocks and walls in exposed situations. Here they may often prepare the way for a richer vegetation later. Owing to their small size they can subsist on very minute quantities of food material, and when they die their decaying bodies mix with the dust resulting from the disintegration of the rocks on which they were growing and form little masses of rich soil on which larger plants can flourish. In such exposed situations they must often be subject to drought, but nothing is more characteristic of them than the rapidity with which they revive after being apparently dried up, a power which they owe to their ability rapidly to absorb water through the thin cell-walls of their leaves as soon as the air becomes damp.

The mosses are the most highly differentiated group on one line of adaptation to land conditions The liverworts, of which Pellia and Marchantia are common examples, form a group of more lowly organized relatives

No differentiation into stem and leaf is to be found in these forms. They are flat, irregularly-shaped structures which cling closely to the surface of the ground by means of the rhizoids which project from the almost colourless under-surface. The upper surface is vividly green, and, in Marchantia, is marked out into tiny diamond-shaped

FIG 76 *Marchantia polymorpha* (From Goebel
ha heads bearing antheridia *l* horizontal branch

areas. The edge becomes broadly lobed owing to the fact that the segments cut off on either side from the apical cell rapidly develop growing points of their own, these grow more quickly than the original growing-point itself, which, therefore, comes to lie in a depression. The internal structure is extremely simple. In Pellia the whole body is merely a flattened mass of parenchymatous tissue containing chloroplasts; in Marchantia there is a slight differentiation which tends to an increase in the exposed surface of the assimilating and transpiring tissue In the centre of each diamond-shaped area is a pore guarded by a vertically placed ring of cells and leading into a cavity from the floor of which project rows of chlorophyll-containing cells. A comparison of these structures with the stomata and intercellular spaces of the base of the

moss capsule is of some interest. The two structures are essentially unlike in their formation, but both are contrivances to secure an enlarged assimilating surface, and there is a certain amount of superficial resemblance.

The antheridia and archegonia of Marchantia are borne on separate, somewhat umbrella-shaped, structures, which

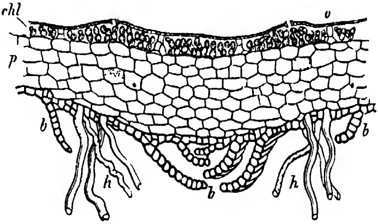


FIG 77 *Marchantia polymorpha*, transverse section through the thallus. (From Goebel)

b overlapping scales on ventral surface
chl rows of cells containing chloroplasts
h rhizoids
o epidermis
p parenchyma.

grow upright from the upper surface of the body (Fig. 76, *hu*). As in the mosses, fertilization must take place under water. The sporophyte, which arises from the oospore, is smaller than that of the moss and is completely dependent on the parent gametophyte, since no assimilating tissue is differentiated. The life-history is in all respects similar to that of Funaria, there being a regular alternation between the independent and comparatively highly differentiated gametophyte and the more or less parasitic sporophyte, which is almost completely given over to the production of spores.

CHAPTER XIX

THE BRACKEN FERN (*Pteris aquilina*) AND ITS ALLIES

THE bracken fern is the commonest and the largest of the British ferns. It occurs abundantly upon heaths and commons, and especially in woods and parks, where the

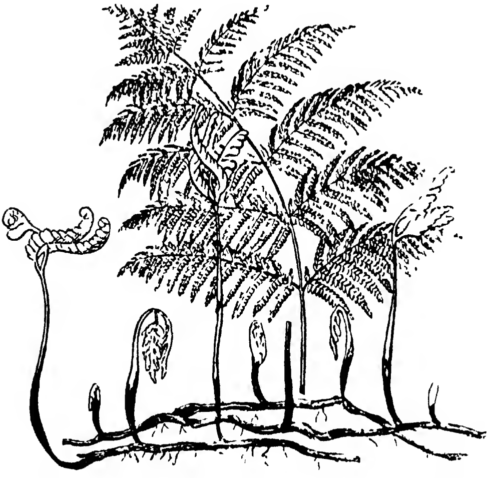


FIG 78 *Pteris aquilina*, rhizome and leaves (From Newman)

green leaves or fronds may attain a height of six feet or upwards. The fronds are somewhat triangular in form and very beautifully lobed. The main leaf-stalk, or rhachis, bears leaflets which consist of stalks bearing

secondary leaflets, and even these may be further subdivided and finely lobed, so that a very delicate tracery of green results. With the first frosts of autumn the green turns to a brilliant golden brown, but it is not till well into the winter that the leaves entirely decay The life of a fern is not affected by the withering of its leaves; the stem persists and sends up new fronds year after year, so that the plant may be termed perennial. The stem is entirely underground, and forms a bulky, rather elongate mass, with a growing-point at the narrower end; it is called a rhizome. It is beset with brown chaffy scales called ramenta which also cover the young leaves and the bases of the old ones The leaves are given off in two lateral rows, and in any given year traces of old decayed leaf-stalks may be seen at one end, then the stalks of the leaf functional at the moment, and, towards the growing-point, the baby fronds for the next few years' growth. A very young leaf consists almost entirely of stalk or petiole, while the blade or lamina is a mere speck (Fig. 79). As it increases in size it is bent closely to the stalk, so that not the delicate tip, but the stronger curved petiole, has to work its way through the soil Many leaves and shoots protect the growing-point in some such way, as may be seen in any garden-bed in the spring The lamina in Pteris remains bent straight back upon its stalk, and thus differs from that of most ferns, which coil inwards in a crozier-like manner in their early growth. When the leaf is full-grown the edges of the lobes are seen to be folded back upon the under surface. Presently this fold is partly lifted and discloses a great number of minute brown bodies below it. These are the sporangia, which are borne just within the margin on the lower surface of the leaf, and are protected by the folded edge till they are ripe

FIG 79 *Pteris aquilina*, two stages in the development of a leaf. (From Newman)

Leaves arise from the sides of the rhizome and grow

upwards. The whole of the lower surface of the rhizome, and, indeed, the bases of the leaves as well, give rise to a number of fine rootlets, which grow downwards into the soil. These are tough and fibrous, and obviously far less simple than the rhizoids of the lower plants The rhizome itself is frequently branched Such branching may be brought about either by division of the growing-point, or by buds arising on the dorsal side of a leaf-stalk near its insertion on the stem

When a rhizome is cut through transversely, even a naked-eye examination is enough to discover that the stem of the fern is much more complicated in its structure than

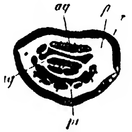


FIG 80 *Pteris aquilina*, diagrammatic transverse section of the rhizome (After De Bary)

ag outer ring of steles *pu* bands of brown sclerenchyma
ig inner row of steles *r* outer ring of sclerenchyma
p soft parenchyma

is that of the moss The ground-substance is yellowish-white, bounded on the extreme outside by a thin dark-brown layer. Immediately within this layer is a band, also dark in colour, broken at the sides so as to allow the yellowish ground-tissue to touch the outside skin Two other bands of this dark tissue lie roughly parallel to those just mentioned, and there are irregular scattered dots of the same nature. Bands and dots of a paler yellowish-brown can also be distinguished from those just described If now a piece of the rhizome be split in a longitudinal direction and the cut surface be examined, the dark-brown outside rind appears merely as a line on either edge of the section, the yellowish ground-substance is seen to constitute the great bulk of the whole stem, filling in between the other structures, while the darker and harder materials, which appeared as dots and bands in cross-section, are now seen to form con-

tinuous strands running the whole length of the stem. The lighter brown strands do not remain distinct for their entire length, but they approach one another and unite, now on this side, now on that, at frequent intervals, and give the appearance of an irregular network. On tracing these various structures towards the growing-point it is seen that in this region the different colours and textures gradually fade out, and at the extreme tip there is a simple soft whitish substance, the structure of which must be studied with a microscope.

If a thin section be cut in a longitudinal direction through the growing-point, mounted in glycerine and examined, a single large wedge-shaped cell will be seen at the extreme tip, with its narrow end turned into the stem and sunk in a pit. As in the moss, new cells are separated off from its inner faces, here only two in number, so that the apex comes to lie in a mass of young actively dividing cells A little way behind the apical cell this tissue begins to differentiate into three layers a single layer of cells upon the outside, which may be traced back to the brown skin or epidermis, as it is called ; a layer several cells thick from which are derived the pale ground-substance and also the hard brown strands—these together are known as the ground-tissue; and finally, in the middle, a mass of cells which is continued backwards into the meshwork of strands referred to above, together forming the stelar tissue.

The epidermis is a single layer of somewhat cubical cells which divide only at right angles to the surface, never tangentially, so that the layer never increases in thickness. From the epidermis arise the ramenta, which consist of many cells arranged as flat plates, but each ramentum is attached to, and in fact derived from, one epidermal cell only The ground-tissue, as we have already seen, consists of two very different parts. The pale yellowish mass is composed of ordinary soft parenchymatous cells, like those of the moss stem, and contains large stores of starch granules. The dark-brown tissue is very different; its cells are long and spindle-shaped, with thickened woody walls. As the thickening of the wall increases, the protoplasm disappears, so that at last these cells are merely empty cases. This tissue is called sclerenchyma, and is a very valuable support to the stem, giving it strength

and rigidity. The lateral lines, where the outermost band of sclerenchyma is wanting, serve for the passage of air into or out of the stem. All the strands of the stelar meshwork are essentially alike in structure, and each strand is known as a stele. Lying centrally in each stele is a cylinder of rather large cells, whose thickened walls have been converted from cellulose into wood. Many of these cells, known as tracheids, are long and narrow, with pointed ends, and the walls are thickened in peculiar ways, a spiral

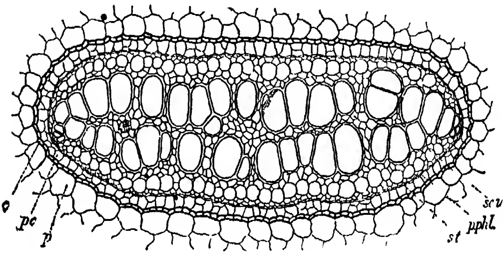


FIG. 81 Transverse section of one stele in the rhizome of *Pteris* (From Darwin)

e. endodermis	*p phl* protophloem
pc pericycle	*sc v* scalariform tracheid
p ground tissue	*s t* sieve tube

line of woody matter may be laid upon the inside of the wall, much as a spiral wire is put inside a gas-pipe, and for the same reason, to strengthen it; or the thickening may be in the form of rings; or, again, it may be laid down with regular gaps of such a kind that in longitudinal section the wall is seen to have ladder-like (or scalariform) markings. The two first kinds of thickening are especially characteristic of the xylem first differentiated at the growing-point, the protoxylem. All thickenings of the wall are, of course, laid down by the activity of the protoplasm in the young living cell. In the fully developed tracheids, however, only the walls are left. Besides the tracheids, there is also a considerable packing of parenchymatous cells with thickened woody walls.

The xylem is partly surrounded by an incomplete ring

of tissue known as phloem, whose most characteristic cells are the sieve-tubes. These are long narrow cells with pointed ends, whose side walls have many areas which are finely perforated all over. Each such area is called a sieve-plate, and these plates have given the name of sieve-tubes to the whole cell. The cell-walls are of unaltered cellulose, and protoplasm is present which is peculiarly rich in nitrogenous material, but no nucleus is seen. The protoplasm is in continuity from one tube to another through the pores of the sieve-plates. Numerous thin-walled parenchymatous cells are also present. The phloem is surrounded by a band of cells, which still forms part of the stele, and is known as the pericycle; this in its turn is surrounded by a specially differentiated layer of cells belonging to the ground-tissue and called the endodermis. Once the stele is fully formed it is incapable of further expansion, and a stele of this type is said to be closed.

The general characteristics of the leaf have been noted already. It is composed of a blade or lamina and a petiole or stalk. With the exception of that part of the petiole which passes underground to join the rhizome, it is green. The blade is compound and divided into leaflets which may be divided in their turn, and the leaves are arranged in two rows along the rhizome corresponding with the two rows of cells cut off from the wedged-shaped apical cell They bear buds for new branches upon the outer side near their origin from the rhizome A nectary is also present near this spot; its function is unknown, but it is said to be visited by ants

The leaf consists of the same tissue systems as the stem, the steles of the leaf being branches from those of the rhizome. The sclerenchyma is well developed, and gives that stiffness to the petiole which enables it to stand erect. Both sclerenchyma and vascular tissue are arranged in such a way as always to present a definite pattern in cross-section, this is thought by some people to be like an oak-tree, and is called 'King Charles in the Oak', while others trace in it a resemblance to a spread eagle, and it was this fancied likeness which led the great Swedish Botanist, Linnaeus (p. 106), to give to this particular Pteris the specific name of 'aquilina'.

Where the petiole gives place to the lamina the steles spread and divide, sending branches throughout the whole substance of the leaf. These become finer and finer by sub-division, so that ultimately only a tiny strand is present, with the xylem and phloem arranged side by side; each stele terminates at last in a single cell. The lamina is flattened horizontally and shows a clearly differentiated upper and lower surface It is chiefly composed of ground-tissue, parenchyma laden with chloroplasts of a discoid form, much like those of the moss. Towards the upper surface of the leaf the cells of this tissue are closely packed together and regular in outline; but beneath they are of an irregular shape, and do not fit into one another, so that spaces are left between the cells. The blade is bounded above and below by the epidermis, the cells of which are flattened and irregular in outline, the irregularities fitting into each other very exactly. The upper epidermis more especially has the cell-walls noticeably thickened, while between it and the green parenchymatous cells is a layer of tissue composed merely of empty cell-walls. Some of the cells in the lower epidermis are modified to serve as the guard-cells of stomata, very like those of the sporophyte of the moss (p. 193), while others grow out into long delicate hairs

A cross-section of a root shows the same tissues as are found in the stem, but there is only a single central stele. The epidermis just behind the tip bears a close growth of root-hairs, each of which is a delicate thin-walled outgrowth from a single superficial cell. These presently get rubbed off, and are absent from the older and higher regions of the root. The ground-tissue consists of parenchyma on the outside and, in the region above the root-hairs, a thick supporting ring of sclerenchyma around the stele. The cells of the endodermis have their radial walls strongly thickened. In very young roots there are two distinct strands of xylem and two of phloem, which are arranged radially, that is, each strand is on a radius, and the xylem and phloem strands alternate with each other in the stele. The protoxylem strands are next the pericycle, the later-formed xylem is differentiated towards the middle of the stele, and by degrees comes to form a solid central

core, so that the stele has much the same appearance as that of the stem.

The growing-point of the root has a single apical cell, shaped like a three-sided pyramid, with its apex directed inwards New cells are separated off from the base, as well as from the three sides, and so the apical cell itself comes to be buried behind a pad of tissue which is known as the root-cap. This cap protects the delicate growing-tip from friction with the soil as the root penetrates downwards, it is itself continually worn away and as continually renewed from behind. Branching of the root takes place by active division in the still young cells just behind the growing-point. The young roots do not, however, appear at the surface for a considerable time, in this way differing widely from the leaves and branches borne on the stem, which are all formed by proliferation of the superficial cells Rootlets arise first by growth of certain cells in the endodermis and gradually bore their way to the exterior. They are therefore said to be endogenous. The biological significance of this method of formation is fairly plain; did the young rootlets appear at the surface in the still actively growing region of the root, and cluster about the apex as the young leaves do about the apex of the stem, they would not only seriously hinder the downward growth of the root, but would themselves get badly damaged by being dragged through the soil. We find, then, that they only break through to the surface at places where active growth has ceased.

The contrast between the structure of the stem, leaf, and rhizoid of the moss and that of the stem, leaf, and root of the fern is obvious. The parts of the two plants have indeed nothing to do with each other beyond the mere fact that they have the same functions to perform in the nutrition of the body. The roots, spreading through the soil, absorb food materials in solution as do the rhizoids of the moss. Not the whole of the root, however, has this power The upper part is strong and hard, and serves merely as an anchor for the rest of the plant body, only the young part of the root just behind the growing-tip has walls thin enough to serve as absorbing organs. Here the surface is greatly increased, and at the same time

it is made possible for the root to cling very closely to the finer particles of the soil, by means of the development of root-hairs (p. 205).

The horizontal stem has nothing to do here with lifting the leaves to the light, that they do for themselves by means of their petioles, but it still acts as an organ of conduction and communication between the leaves and roots. The steles are the channels along which the sap passes, and a far more perfect differentiation is found than obtains in the central cylinder of the moss stem. The distinct functions of xylem and phloem are more readily made out in the flowering plants, where such an arrangement of the parts occurs that it is possible to experiment by cutting away the phloem from a given region of the stem, leaving the xylem intact. When this is done it is found that the roots gradually wither away, while the leaves remain fresh and green till the roots are too dead to absorb nourishment from the ground When the cut is made to include the xylem, on the other hand, the leaves perish immediately. From these results the conclusion has been drawn that the xylem acts as a channel for the upward current of salts in solution from the roots, while the elaborated food material is distributed from the leaves to the other parts of the plant through the sieve-tubes and parenchyma of the phloem. The leaves themselves are specialized as organs for the elaboration of carbohydrates, and for the interchange of gases with the air. With regard to the latter, the contrivance already noticed in the sporophyte of the moss (p. 193) is here further developed The cells of the epidermis are protected on their outer walls, but, by means of the intercellular spaces and the stomata, a far greater surface of the thin cellulose walls of the living cells is exposed to the air than would be the case were the whole leaf formed of a single layer of thin-walled cells, as in the moss. Yet with all this exposed surface the danger of excessive transpiration, when the air is dry, is avoided by a collapse of the guard-cells, so that communication with the outer air is cut off.

It now remains to describe how reproduction is carried out in the fern. It has already been noticed (p. 200)

that the edges of the leaflets are folded back upon the under surface, and that the sporangia lie under these folds. If the fold is lifted they are found to be further protected by a transparent membrane called the indusium. They are seated upon a pad of tissue known as the placenta, extending all along the under side of the leaflet, and each is derived from a single epidermal cell. The sporangium is a little stalked capsule with a single-layered wall containing a large number of spores. In appearance it resembles two watch-glasses fastened together by a thickened rim

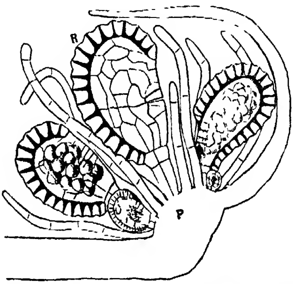


FIG 82. *Pteris*, transverse section through the edge of a leaf with sporangia (From Darwin.)
P. placenta R annulus of empty sporangium

consisting of a row of cells called the annulus. When the sporangium gets dry the annulus contracts and exerts a pull on the thin walls, so that they split and give an exit for the spores. These are somewhat triangular in shape, and so tiny that they are easily blown about by the wind Given favourable conditions of temperature and moisture (a damp tile is a convenient place on which to sow them for observation), after a period of rest they germinate, and, as the result of active growth and cell-division, a small green plant called a prothallus is formed. The prothallus is flat and heart-shaped, and it grows close to the ground, so that a kind of little damp chamber is formed underneath it, where moisture will collect and be kept from drying up. The growing-point

of the plant lies in the dent between the two lobes ; a band behind it is thick and composed of several layers of cells, while the lobes are formed of a single layer only. All the cells of the body are parenchymatous and contain chloroplasts. From the under side white unicellular rhizoids arise and serve to anchor the prothallus, and also to supply it with watery solutions for food Soon little protuberances appear upon the under surface, and may be recognized as antheridia and archegonia from their

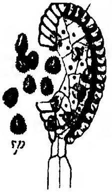


FIG 83 *Pteris aquilina*, a burst sporangium (From Howes)
an annulus
sp. spore

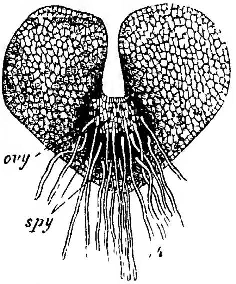


FIG 84. *Pteris aquilina*, a mature prothallus (From Howes)
ovy. archegonia
rh rhizoids
spy antheridia.

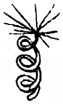


FIG 85 *Pteris aquilina*, ripe spermatozoid (From Howes)

resemblance to those of the moss, they mark the prothallus as a gametophyte The antheridia, which may be scattered anywhere, are rounded bodies with a wall one cell thick. They contain numerous spermatozoids bearing at one end a tuft of many cilia, and spirally coiled within the parent-cells. The archegonia are borne on the median cushion near the growing-point, like those of the moss, they are flask-shaped, but the venter is sunk in the substance of the cushion. When the canal-cells break down they form mucilage containing a small quantity of malic acid, which exudes into the water collected in the damp chamber under the prothallus, and serves to attract

the spermatozoids which are swimming near. One spermatozoid passes down the neck and fuses with the egg-cell to form the oospore. This at once surrounds itself with a cell-wall, and proceeds to divide, and at length a new fern plant which will bear spores is developed. It is interesting to note that at the first division the oospore is divided into two cells, one of which represents the shoot, the other the root of the future sporophyte. From the root-cell is also developed an organ which is of use only to the embryo, and may therefore be termed a larval organ: this is the foot which, like a root, serves for attachment and absorption of food, but in this case both the attachment and food are afforded by the gametophyte, so that for a time the young fern lives as a parasite on its parent. This relationship recalls that of the sporophyte to the gametophyte in the moss, which, however, is permanent throughout its life. The fern gradually develops leaves and roots of its own, the work of the prothallus is done, and it dies away. Curiously enough, the functional roots are not derived from the original embryonic root, which disappears very early. For this reason they are known as false or adventitious roots. As already described (p. 207) they may spring from any part of the rhizome or from the leaf bases.

The following table represents the life-history:—

```
            Fern-plant  (Sporophyte)
                |
            Sporangium
                ||
              Spore  (Gametophyte)
                |
            Prothallus
              /    \
     Antheridia      Archegonia
         |               |
   Spermatozoid _____ Ovum
                ||
             Oospore  (Sporophyte)
                |
            Fern-plant
```

Like that of the moss the life-history of the fern presents an alternation of generations, but the relative size of the generations in the two plants is reversed. In the moss,

what we call the plant, the dominant generation, is the gametophyte; in the fern it is the sporophyte. The sporophyte of the moss looks like part of the gametophyte, and is popularly called the 'fruit', the gametophyte of the fern is an insignficant little prothallus. There are, however, points of resemblance between the corresponding generations other than the production of spores by the one, and of gametes by the other. Both gametophytes are of simple structure, and show but little differentiation of cells; thus both are fixed to the ground by simple rhizoids. Both sporophytes, on the other hand, exhibit greater structural complexity, as shown, for instance, by the presence of stomata in both, and each lives for a longer or shorter time as a parasite upon the gametophyte.

From the preceding description it will readily be understood that in becoming adapted to life on land, ferns have followed a very different line of evolution from that pursued by the mosses. Both show their origin from aquatic forms in the motile spermatozoids, and both develop non-motile spores at a definite stage in their life-history for purposes of distribution on land, but whereas in mosses the gametophyte is chiefly developed, and is the larger and more independent, while the sporophyte arises as a mere appendage upon it, in the ferns the gametophyte is always small and simple, obtaining the necessary moisture for fertilization by clinging close to the ground, while the sporophyte attains to an independent life of its own. Thus set free from the gametophyte, the sporophyte becomes highly differentiated, and may grow very large, as, for example, in some of the ferns of the tropics, where the erect stem covered by the sheathing leaf bases may grow so tall as fully to justify the term 'tree-ferns'

In Pteris any of the fronds may produce sporangia, but in other forms various degrees of differentiation into spore-bearing and vegetative fronds occur In the parsley fern, for instance, the delicate spreading foliage leaves are readily distinguishable from the more compact spore-bearing fronds In Osmunda each frond is differentiated into two parts, only the terminal portions bearing spores, while in the moonwort (Fig. 86) and the adder's tongue, a definite spike for spore-bearing is produced from the base of each leaf.

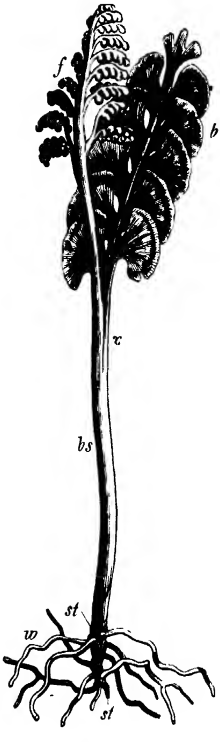


FIG 86 *Botrychium lunaria* (moonwort) (After Goebel)
b sterile lamina.
bs leaf-stalk
f fertile lamina
st stem.
w roots
x point of branching of the stem.

In a few little-known forms differentiation has proceeded in another direction, in that two kinds of spores are produced. The same phenomenon occurs in a much better known plant, Selaginella, which, though it is more nearly related to the club mosses than to the ferns, belongs with them to the great group of non-flowering vascular plants, of which Pteris has been chosen as an example.

In Selaginella the stem creeps on the surface of the ground and bears little, somewhat oval leaves of two sizes. The fertile branches are upright and bear rather crowded leaves of one size only. Sporangia are borne on the stem, in the axils of the leaves, instead of on the leaves themselves as in ferns (Fig. 88, A), and are of two kinds, microsporangia, which contain a great number of small spores, and mega-sporangia, which contain only four large ones. Development of the megaspores begins before they leave the sporangia, but ultimately both kinds of spores are shed on to the damp ground below. In both cases, though cell-division continues for a time there is very little increase in size, and the prothallus remains as a mere rudiment. In the structure developed from the microspore all the cells but one go to form part of a single antheridium, that one alone

apparently representing the vegetative part of the prothallus in the ferns. The spermatozoids are set free from the antheridium by rupture of the wall in the usual way, and swim in the surface film of water on the ground The megaspore develops into a slightly larger prothallus, which is, however, only just big enough to rupture the old spore-

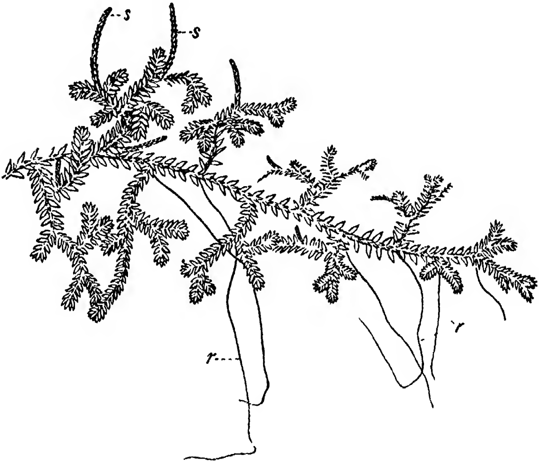
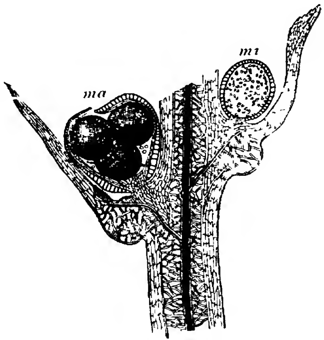


FIG 87 Selaginella (After Scott)
r rhizophores s. fertile spikes

case, and project from it at one end (Fig. 88, B). Here it may become attached to the ground by a few rhizoids. Archegonia, essentially resembling those of the fern, are formed also at this end, and an active spermatozoid may enter the neck of each archegonium and fuse with the ovum. Here the independence of the sporophyte is carried still further than in the ferns; in fact the original dependence of the sporophyte on the gametophyte for its nourishment is merely indicated by the outgrowth from the embryo



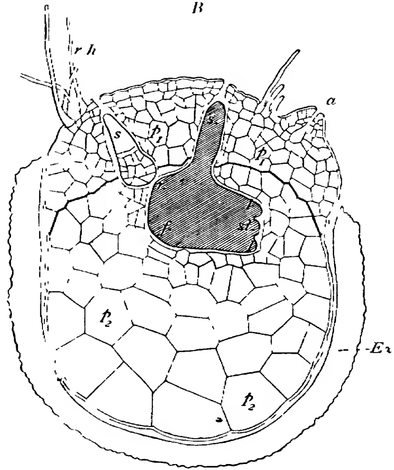


FIG 88

A. Part of a longitudinal section through a fertile spike of Selaginella (After Dodel Port from Scott)

ma. megasporangia dehiscing

mi microsporangium.

B Longitudinal section through a prothallus derived from macrospore (After Pfeffer)

a. unfertilized archegonium. *Ex* wall of macrospore *f* foot *l l.* first leaves p^1 p^2 prothallus. *r.* root of embryo. *rh* rhizoids. *s* embryo sporophyte. *st* stem

of an absorptive 'foot', which penetrates the substance of the prothallus. In Selaginella, indeed, it is the gametophyte which has become dependent, for that at least which is developed from the microspore is totally dependent upon nourishment already stored in it by the activity of the sporophyte.

CHAPTER XX

THE PINE-TREE (*Pinus sylvestris*)

THE Scots' Pine is one of the commonest of our English cone-bearing trees. It is familiar in sandy regions, and often flourishes best in places where no other trees will grow luxuriantly. It grows also in the far North, and on high steep mountain ridges where the climatic conditions are too severe and the soil too scanty for beeches, oaks, and other trees which flourish on the lower slopes In such places even dense forests of pines may occur, their dark evergreen foliage forming a somewhat sombre feature in the landscape. When the leaves are shed they lie for a long time on the ground without rotting, making the characteristic springy carpet of 'pine-needles', which, together with the absence of light all the year round, makes it possible for very little undergrowth to find a sufficient means of subsistence

Stem, leaves and roots can be readily recognized and are strictly comparable with the corresponding parts of the fern, though differing widely from them in their outward form The roots are thick and strong towards the stem but taper to a fine delicate tip. Unlike those of the fern, they form a definite well-developed and much branched system, all the roots arising ultimately from a single main root, the youngest nearest the growing point, the oldest farthest away The same is true of the stem, for all the branches at the top of the tree can be traced back to their origin in the single erect, thick, woody main stem which forms the trunk. The method of branching is thus unlike that of the fern, branches never arise by division of the apical growing-point, but always at definite intervals down the stem, at points just above the insertion of the leaves, in the angle between the leaf and the stem. The branches are of two kinds; some of them repeat in their structure that of the main stem, and have an unlimited power of growth by means

FIG 89. A Pine-branch bearing cones in the late spring. *br.* last year's branches of limited growth *br*¹ current year's branches of limited growth with leaves just unfolding *c*¹. current year's cone. *c*² cone a year old *l* foliage leaves. *sc.* scale leaf. *sc.b.* hardened base of scale leaf

B. Ovule-bearing scales. (After Strasburger)

of their apical growing-point; others, known as branches of limited growth (Fig 89, *br.*), never attain to a greater length than about half or three-quarters of an inch. The foliage leaves (*l*), the so-called needles, only occur on branches of this latter description, and always grow two together at the apex of a branch. They are thick and narrow, with a perfectly simple outline, and form a most striking contrast to the much-divided fronds of the bracken. When they die the whole branch is shed from the tree, together with its pair of leaves, and hence it comes about that the needles are nearly always found on the ground in pairs. The leaves that arise on the main branches are hard, dry, and brown, and grow so close together that they form a complete covering for the young stem. These are the hardened bases of the papery scales which are found in the spring protecting the young branches as they open from the bud (*sc*), the upper part is shed when the buds open, but the old bases remain firmly attached to the stem. The buds are formed in the late summer and autumn, chiefly at the ends of the long branches, and, as rudimentary stem, leaves, and branches are already present, the fresh young leaves can appear much more rapidly in the spring than they would be able to do were no winter buds formed

A microscopic examination reveals that the same kinds of tissue-systems occur in Pinus as in Pteris, but a different arrangement of the parts obtains. In a cross-section of a stem a few months old a thin layer of ground-tissue can be recognized surrounding a single central stele, and surrounded in its turn by an epidermis. The latter is not very clearly seen on account of the closely crowded leaves, which make the whole outline of the section rough and jagged. In the stele, xylem and phloem can be recognized, the latter forming a ring outside the former; but the two are separated by a third band of tissue not represented in the fern, made of small brick-shaped actively-living cells with thin walls, this is the cambium Moreover, another difference is at once observable in the presence of a core of empty thin-walled parenchymatous cells which form a mass of pith in the centre of the xylem Bands of parenchyma also radiate from the pith towards the outer ground-tissue and are known as medullary rays. The whole stele

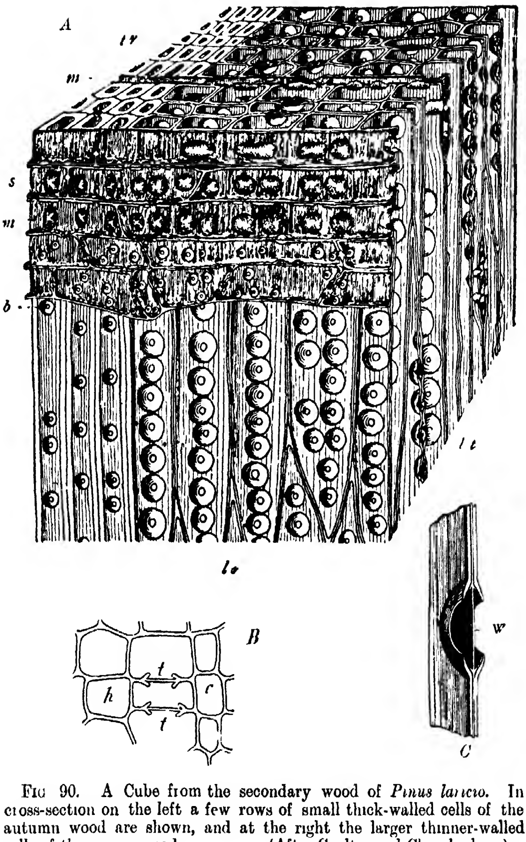


Fig. 90. A Cube from the secondary wood of *Pinus laricio*. In cross-section on the left a few rows of small thick-walled cells of the autumn wood are shown, and at the right the larger thinner-walled cells of the spring wood (After Coulter and Chamberlain.)

b bordered pit *lr* longitudinal section. *lt.* longitudinal tangential section *m.* medullary ray *s.* simple pit. *tt* transverse section

B, C Diagrams illustrating the structure of bordered pits (After Sachs.)

c cambium cell *h* cell of wood parenchyma *t.* tracheid with pit *w* middle partition

is surrounded by pericycle and endodermis. If, now, this single stele is traced up towards the growing-point, the difference between its structure and that of a stele in a fern-stem becomes more and more apparent. A short distance behind the growing-point the pith is very large, and is continued outwards by such wide bands of parenchyma that the xylem and phloem are reduced to mere isolated threads known as bundles, each consisting of an inner mass of xylem, an outer mass of phloem, with a layer of cambium between the two. The arrangement of parts here is known as collateral. Owing to the presence of cambium these bundles possess the power of almost unlimited growth, and are, therefore, distinguished as 'open' (cf. fern, p. 204), for the cambium is, in fact, nothing but a layer of embryonic tissue which has the power of active growth and division. The cells which are cut off from the inner side are gradually differentiated into xylem, those on the outer side into phloem, and so an increasing amount of stelar tissue is formed and the stem gradually grows in bulk. The ring of xylem is made complete by certain cells in the parenchyma between the bundles becoming active also, and forming what is known as interfascicular cambium It is to be noticed that the protoxylem projects into the pith while the most recently formed xylem lies most to the outside.

The xylem throughout Pinus is formed entirely of tracheids and wood-parenchyma In the protoxylem the tracheids have the usual spiral and annular thickenings (p. 203), but in the very regularly arranged tracheids of later formation the thickening is laid down in such a way as to leave a number of peculiarly shaped pits in the lateral walls. When looked straight down upon, as in a tangential section of the whole stem, the pits present a very characteristic double outline (Fig. 90 A, *b*), which has gained for them the name of bordered pits. In transverse section (Fig. 90, B, C) it is seen that this is due to the narrow pore, which faces the lumen of the tracheid, widening out in the thickness of the wall, so that the whole space is like a funnel with its wide end against the middle partition. By these pits the sap can pass from one tracheid to another, and even from the tracheids into the medullary rays.

The formation of tracheids by the cambium is necessarily

intermittent owing to the whole tree's being practically dormant during the winter months. With the revival of activity in the spring, growth becomes exceptionally rapid and the cells then formed are larger than those formed later in the year. The lighter open-grained spring wood, coming in contact with the darker closer-grained tissue of the previous autumn, forms a sharply defined line, which gives the ringed appearance characteristic of timber trees, by means of which their age can be determined.

The medullary rays are formed by the cambium's giving rise at definite places to ordinary thin-walled parenchyma instead of the usual xylem- or phloem-cells. Those which run like the spokes of a wheel from the pith to the outer edge of the stele represent and continue the spaces between the original bundles, and are called primary, to distinguish them from those which begin in the wood of later years and are known as secondary rays.

The structure of the phloem calls for no particular remark. It consists of sieve-tubes and thin-walled parenchyma, as in the fern, and protophloem and secondary phloem are essentially alike. As growth in thickness takes place inside the stem, the outer epidermis, unable to stretch sufficiently to keep pace with the increasing bulk, becomes cracked and broken. The inner tissues are, however, protected from injury by a formation of cork, which arises from the active division of a layer of cells just below the epidermis, known as the phellogen. These cells grow and divide like the cambium, and the cells on the outer side become thick-walled and corky and lose their protoplasm. An effectual protective layer is thus formed, but one which, being dead, has no power of growth, and is bound in its turn to be outgrown and rent apart by the actively living cells within. Every year, then, a new layer of cork must be formed, but the old layers need not necessarily be shed, and ragged, hardened fragments of them always remain on the pine and cause the rough uneven surface of the bark.

Throughout the stem and, indeed, in all parts of the plant, there are found channels containing resin. These resin ducts are formed as regularly arranged intercellular spaces, the cells adjacent to them forming a definite epithelial layer which secretes the resin. The use of resin is

somewhat uncertain It exudes in considerable quantity when the tree is injured, and perhaps acts as an antiseptic dressing for the wound. It certainly helps to protect the tree against the attacks of animals.

The growing-point of the stem is different from that of either a fern or a moss in that no single apical cell can be distinguished. At the extreme tip is a mass of small actively dividing cells. A little way behind the tip the zones which give rise to epidermis, ground-tissue, and stele respectively become gradually differentiated, and in the latter appears a single circle of threads which are the

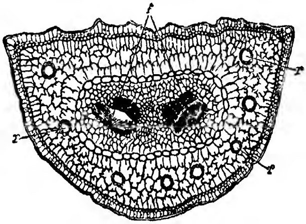


FIG 91 *Pinus laricio*, transverse section of a leaf (After Veitch, from Rendle)

f pair of bundles *r* resin canals

beginning of the vascular bundles From these rudiments all the tissues of the stem are gradually developed. Leaves arise by growth of the peripheral cells just behind the actual tip Once formed, they grow faster than the growing-point itself, so that the latter becomes hidden and protected by the young leaves, some of which are specially modified for this purpose (p. 218)

The foliage leaves of the pine, as already pointed out, are not borne directly upon the main stem or its longer branches, but upon special branches of limited growth. Each leaf is flattened on its upper surface, rounded on the lower, and is almost, if not quite, as thick as it is wide. Lamina and petiole cannot be distinguished. One bundle from the stem penetrates each leaf, and there divides into two strands which lie side by side near the middle of the leaf

and do not give off branches (Fig. 91, *f*). Around them is a mass of colourless tissue composed partly of empty cell-walls with pits and partly of living cells, whose walls have no pits. These two together constitute the so-called 'transfusion tissue', and will be referred to again later (p. 225). This mass of tissue in which the bundles lie is surrounded by a well-defined pericycle, outside which are several layers of thin-walled parenchyma with curiously folded walls and containing chlorophyll Resin ducts are present, but otherwise there are very few intercellular spaces and no marked differentiation exists between the mesophyll of the upper and lower surface. The outer layers of the cortex are sclerenchymatous (p 202), while the epidermis itself consists of fibre-like cells lengthened parallel to the long axis of the leaf with strongly thickened walls. The stomata are few, and the guard-cells are sunk below the surface.

About the arrangement of the tissues in the root not very much need be said, for in a young root it is essentially similar to that already described in the fern. The peculiarities of minute structure, however, which were noted in the stem occur also in the root Two xylem-bundles alternate with two phloem-bundles, and these are surrounded by a pericycle which is many cells thick As in the fern the protoxylems lie on the outside against the pericycle, and a complete xylem-plate is formed later uniting the two. The central pith, which was found in the stem, does not exist here A cambium layer is present just inside each phloem-bundle, separating the latter from the xylem The ring is completed by certain cells in the pericycle opposite the protoxylems becoming capable of active division and forming tissue comparable with the interfascicular cambium of the stem. New xylem is then formed on the inside, new phloem on the outside, and the root comes to show annual rings like those of the stem. Meanwhile a development of cork has been taking place, by the activity, not, however, of the cortex, but of the pericycle. Nourishment is thus cut off from the outer layers, and the whole of the cortex gradually withers away. After this secondary thickening has begun the root is, of course, incapable of absorption, but it forms an in-

creasingly firm and strong support for the increasing weight of the plant. The growing-point of the root is like that of the stem in being multicellular, like that of the fern-root in having a root-cap. No very clearly differentiated epidermal layer can be made out, and the root-cap seems to be a mere extension of the young cells of the ground, tissue over the delicate growing-tip Differentiation of the tissues takes place much as in the stem, allowing for the different arrangement of tissues in the stele Young rootlets arise endogenously, as in the fern, this time, however, by growth of the pericycle.

The various life-processes of the plant are carried on in essentially the same manner as in the fern. Certain special points may, however, be noticed as showing how the two have become adapted to different environments. Perhaps the most striking difference is the very small surface which the leaf of Pinus exposes. If this be considered in connexion with the thick firm outer covering, the absence of intercellular spaces, and the sunken, protected position of the stomata, it becomes obvious that the possibility of gaseous interchange between the leaf and the air is very much smaller than in the fern. This must have far-reaching results , only one will be mentioned here, namely, that the amount of water vapour transpired from a given surface of a pine leaf must be enormously less than that transpired from the same surface of a bracken frond The contrast is still more striking if almost any other fern be chosen instead of the bracken. Now pine-trees are most often found in open exposed situations, and growing either on sandy soil, which is very porous and consequently holds but little water to supply the place of that lost by transpiration, or on steep hill-sides, where the water flows away quickly. Obviously, then, it is an advantage that the plant should transpire little. Further, protection is needed through the winter, for each leaf lives several years, and the tree might suffer severely did active transpiration take place through the cold winter months. If transpiration be hindered there will be a comparatively sluggish circulation of sap through the tree. In this connexion the entire absence of true vessels, such as will be described in the next chapter, is interesting,

and also the fact that *Pinus sylvestris* itself, our only British species, has no root-hairs, and, therefore, possesses a comparatively small absorbing surface A small fungus seems, however, habitually to grow in close contact with the tips of the roots, which probably derive moisture from the hyphae; these, therefore, may serve in the place of root-hairs. Attention may be drawn here to the curious absence of branching in the vascular bundles of the leaf. It seems at first sight that there is but scanty provision for the distribution of food material. Apparently, however, the transfusion tissue acts as a kind of extension of the vascular bundles, the pitted cells playing the part of extra xylem, the non-pitted cells with contents acting as extra phloem, but the arrangement is by no means as perfect as the delicate ramifying system of bundles found in the fern.

A further striking physiological difference between the pine and the fern arises from the tree-habit of the former. The power of growth in thickness is naturally connected with the need for support of the yearly increasing bulk of the plant. The growth in height introduces a new difficulty, that of raising a large quantity of fluid from the ground to the leaves In small plants like the mosses this rising of the sap may probably be explained as brought about by osmosis. In high trees like the pine such an explanation is wholly inadequate, and no satisfactory explanation has yet been given. The question will be further discussed in the next chapter (p. 236).

As in the fern, the reproductive cells produced by the pine-tree are spores, and the whole tree, therefore, is a sporophyte. There is here a more striking differentiation than occurs in any of the ferns between the portions of the plant concerned with nutritive processes and those which bear the reproductive organs. These latter are borne on short thick branches known as cones, which are composed of a central axis carrying thickly clustered and specially modified leaves in connexion with which the sporangia are produced (Figs. 89, 92). The spores are of two kinds, megaspores and microspores, and are borne on separate cones. The cones bearing microspores arise near the base of a year's growth (Fig. 92, I), and ripen in May, before the foliage leaves higher up on the same

shoot are fully developed. Those bearing megaspores occur near the top of another shoot (Fig. 89); they are much less numerous and ripen rather later.

The microsporangia arise on the lower side of the closely-set leaves of the cone, two on each leaf. A group of cells

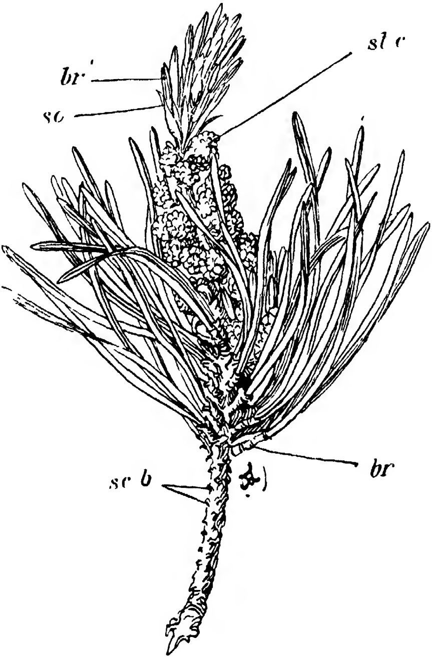


FIG 92 I

I Twig of *Pinus sylvestris* bearing microsporangia.

br, *br*[1] branches of limited growth.

sc scale leaf

sc b hardened bases of scale leaves

st.c cones bearing microsporangia.

lying just below the surface on either side divides repeatedly, and each gives rise finally to a mass of spores which, as they grow at the expense of the surrounding tissue, soon come to lie in a cavity of considerable size. As in the megaspores of Selaginella, germination begins before the spores are scattered, but only a single cell-division takes place at this

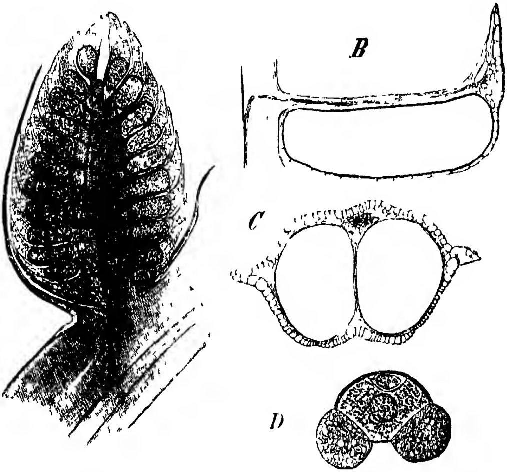


Fig 92 II *Pinus pumilio* (After Strasburger)
A Longitudinal section of cone bearing microsporangia
B Longitudinal section of a single scale leaf with microsporangia.
C Transverse section of the same
D Ripe pollen-grain of *Pinus sylvestris*

stage. The body thus formed, however, which is shed from the sporangium as a ripe pollen-grain, is no longer a spore, but corresponds to a baby prothallus. The whole grain is curiously shaped. It is surrounded by two coats, the outer of which forms two bladder-like projections filled with air (Fig. 92, II, D). These reduce the specific gravity of the body and enable it to be readily blown about by the wind.

The structure of the cones which bear the megasporangia is slightly more complicated than that just described. The sporangia arise on the upper surface of large firm scales, which in their turn grow each from the base of a tiny scale leaf (Fig. 89) The latter is often regarded as the real spore-bearing leaf, but the modifications which have taken place are very difficult to trace At the base of each of the large scales two little pads of tissue arise, each of which becomes differentiated into an inner mass, the megasporangium (nucellus) and an outer integument. The latter is never quite closed, but at one point, known as the micropyle (Fig. 89), allows the nucellus to be exposed. Each body is now known as an ovule. Division of special cells within the megasporangium to form spores occurs in the usual way, but finally only one large megaspore (the embryo sac) is produced As with the microspores, so here, germination takes place within the sporangium The prothallus (endosperm) grows at the expense of the surrounding tissue and becomes much larger than that which arises from a microspore. Dehiscence of the sporangium never takes place. Presently archegonia are formed in the prothallus. These are few in number and somewhat rudimentary in structure, but readily recognizable by their form. The cells of the wall of the venter are indistinguishable from the surrounding tissue in which the archegonium is completely buried Four small cells represent the neck, and below them is a small ventral canal-cell and a relatively enormous ovum (Fig. 93)

The method by which the two gametes come together is totally different from anything hitherto described, and is of peculiar interest as showing the adaptability of the plant to new conditions. The baby prothallus derived from the microspore, which, as already pointed out, is small and very light, is carried by the wind to the surface of the megasporangium where the latter is exposed at the micropyle Of course the chances are very great that a given pollen-grain will not reach the exact spot where it is required , enormous numbers must necessarily be wasted, and hence the great production of pollen, which often causes the whole air in the neighbourhood of a pine-tree to seem full of fine dust when branches bearing the ripe cones are shaken by the wind. Wasteful,

however, as this method of carriage may seem, it represents for the plant a new independence which has far-reaching results.

When the pollen-grain reaches the micropyle the megaspore has not yet germinated, and the growth of the

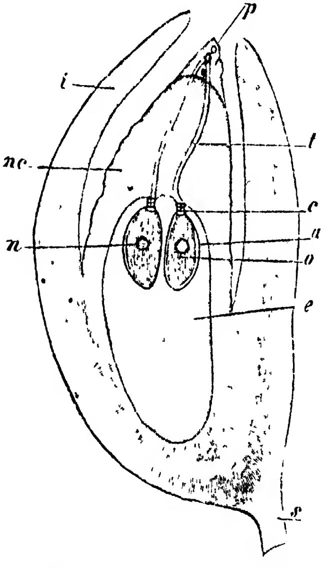


FIG. 93. *Picea vulgaris*, median longitudinal section of an ovule. (From Strasburger.)

a. archegonium	*nc* nucellus.
c neck of archegonium	*o* venter of archegonium
e. endosperm	*p*. pollen-grains
i integument	*s* seed wing.
n nucleus of egg-cell	*t* pollen-tube

prothallus and development of the archegonia occupy a full year. Meanwhile the pollen-grain grows, sending a long tube through the substance of the megasporangium, from which, probably, it derives its sustenance. There

is some further cell-division, but the prothallus never comprises more than four cells altogether, of which two are microgametes. It is, of course, never capable of independent life, and it is noticeable that the microgametes themselves are without cilia and therefore incapable of locomotion. Together with one of the vegetative cells, they enter the long pollen-tube, which reaches the neck of an archegonium in the June of the year following the arrival of the pollen-grain. One of the microgametes passes through an opening in the wall of the tube, traverses the intervening protoplasm, and its nucleus fuses with that of the ovum.

Fertilization is now complete, the oospore surrounds itself with a cell-wall, and the young embryo begins to

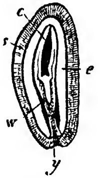


FIG 94 *Pinus pinea*, longitudinal section through the middle of a seed (From Sachs)

c. first leaves
e endosperm
s. seed coat
w rudiment of root
y micropylar end of seed.

develop. By the growth of a peculiar embryonic organ known as the suspensor, the cells which finally will give rise to the actual adult plant are pushed forward, and come to lie embedded deep in the prothallus, which provides them with nourishment as growth proceeds. If all the archegonia are fertilized, several embryos begin to develop side by side, but eventually one gains the upper hand, and the others gradually die away. By degrees the parts of a young plant become differentiated, and rudimentary root, stem, and leaves are distinguishable (Fig. 94).

The prothallus is largely absorbed, but part persists surrounded still by the remains of the megasporangium, and this, in its turn, by the integument, which has by now

grown out at the top to form a long spreading membranous wing. The whole complicated structure is known as the seed, and all that has taken place since the act of fertilization constitutes the process of 'ripening'. The seed is now ready to be shed, and becomes detached from the scale which bears it. The scales of the cone, which by this time have become hard and dry, bend outwards and separate from each other. The light wing of the seed catches the wind, and so it is blown away from the parent plant. The young plant within the seed meanwhile remains dormant. When sufficient warmth and moisture are supplied it begins to grow again, bursts the seed-coat (the old integument), and sends its root down into the ground, its young leaves up into the light and air. Not until this is accomplished can it begin to feed itself, but for the early stages of germination it is still supplied with food material stored by the activity of the last sporophyte generation in the cells of the prothallus.

The following table represents the life-history :—

Pine-tree (Sporophyte)

Microsporangium (pollen-sac)	Megasporangium (nucellus)
‖	‖
Microspore (Gametophyte) (pollen-grain)	Megaspore (Gametophyte) (embryo sac)
|	|
Prothallus	Prothallus (endosperm)
	|
	Archegonium
	|
Generative Cell	Ovum

‖

Oospore (Sporophyte)

|

Pine-tree

CHAPTER XXI

THE SUNFLOWER (*Helianthus annuus*)

The pine-tree is a flowering plant in the strict sense of the word, as will be explained later, but the cones of the pine differ in important ways from the blossoms of a buttercup or a rose, and in a popular sense the word flower is applicable in a different degree to these. The sunflower has been chosen to represent plants bearing flowers of this latter kind.

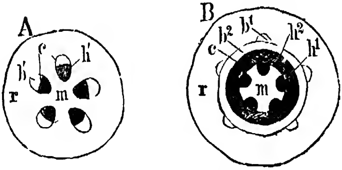


FIG 95 Diagrammatic transverse sections of stem showing growth in thickness (From Vines)

A Very young, there are five isolated bundles
B After growth in thickness has begun

b^1 protophloem
b^2. secondary phloem.
c cambium
h^1 protoxylem
h^2 secondary xylem.
m pith
r. cortex

As in the pine, there is a single main root bearing rootlets, and a single main stem bearing leaves and branches. The green foliage leaves are borne directly on the main stem, and are differentiated into petiole and lamina; they show a wide and slightly swollen leaf-base just where they join the stem. The branches are borne in the axils of the foliage leaves, and there is no such distinction between branches of limited and those of unlimited growth as occurs in the pine.

If the young stem be examined even with the naked eye,

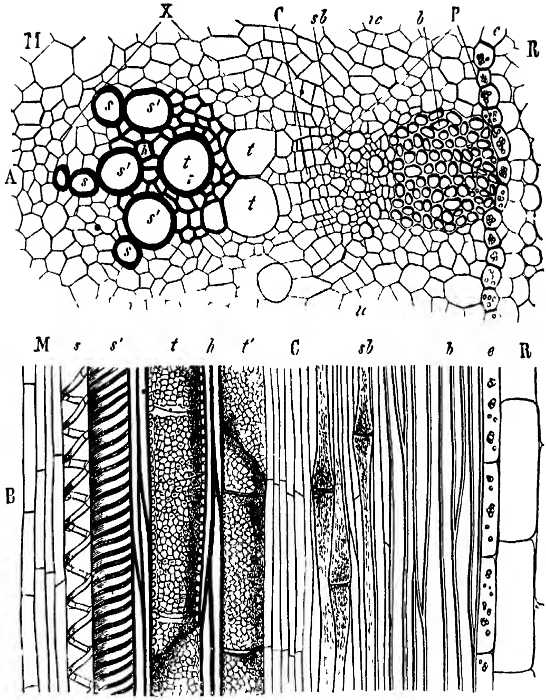


FIG 96 Sections of a vascular bundle of the stem of the sunflower (From Vines)

A Transverse

b fibres of the pericycle
h wood fibres
ic interfascicular conjunctive tissue.
s small spiral vessels
s' large spiral vessels (protoxylem)
sb. sieve-tubes.

B Radial vertical

t pitted vessels
t' pitted vessels in course of formation from the cambium
C cambium
M pith
P phloem and pericycle
R cortex
X. xylem.

it will be found to consist of essentially the same parts as a very young stem of Pinus. A single circle of vascular bundles lies embedded in a mass of soft ground-tissue, which is white in the middle, greenish on the outside. The whole is surrounded by a thin epidermis. The tissues in each bundle are arranged like those of Pinus, but their minute structure presents some peculiarities. The xylem is characterized by large tubular structures which are round in cross-section, very long in longitudinal section. These are the vessels from which the whole tissue has received the name of vascular tissue. Each represents a longitudinal chain of cells, whose dividing walls have been absorbed, so that the whole chain forms a single uninterrupted tube. The walls are thickened in the spiral, annular, or reticulate manner described for tracheids (p. 203), and the protoxylems always have vessels with spiral or annular thickening. The advantage of these tubes over tracheids, with their much more numerous dividing walls, will be readily appreciated Tracheids and wood parenchyma are also found packed in amongst the large vessels, and the whole of the wood has a much more irregular appearance in cross-section than that of Pinus. Many of the tracheids are pitted, but the peculiar bordered pits of Pinus (p. 220) do not occur. The phloem also is rather different from that of either the fern or the pine. Sieve-tubes are present, but the sieve-plates, instead of being on the lateral walls, are formed in the dividing walls between cells of a single longitudinal row. The walls are, of course, only partly absorbed, not wholly as in the vessels of the wood, and so the sieve-tubes remain cells, and are not true vessels. Each sieve-tube has associated with it a narrow thin-walled cell, very rich in protoplasm; this, on account of its position, is known as a companion cell. The function of these cells is somewhat doubtful, but as they are often found packed with starch-grains it seems probable that some of the surplus carbohydrate material which is being conveyed through the sieve-tubes passes into the companion cells, becomes reconverted into starch, and is at any rate temporarily stored there. As the sunflower is an annual, no great thickening of the stem ever occurs, but in the flowering shrubs and trees, where there is an annual increase of leaf

surface, regular secondary thickening takes place by means of the cambium, as in the pine, and corky layers are formed from a phellogen layer in the cortex.

The roots are like the roots already described as regards the arrangement of the tissues, and the only features to which attention need be called here are that there are

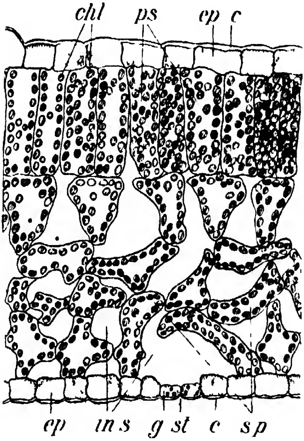


FIG. 97 Transverse section of the leaf

c. cuticle.
chl. chloroplast
ep epidermis
g guard-cell.
in s intercellular space.
ps. palisade tissue.
s p. spongy parenchyma.
st. stoma.

often at least three xylem and phloem bundles, and that the pericycle consists of a single layer of cells.

The structure of the leaf differs widely from that of the pine leaf, and more nearly recalls that of the fern. Three vascular bundles pass up each petiole. The greater part of these forms a strong midrib, from which branches are given off on either side These branches subdivide

repeatedly, and form a delicate network through the whole soft green tissue of the leaf. In the mesophyll two regions are readily distinguishable under the microscope. Just under the epidermis is a row of long narrow cells, elongated in the direction of the thickness of the leaf, closely packed together and containing numerous chloroplasts These form the palisade tissue. Below them is a loose mass of rounded cells with many large intercellular spaces which communicate with the exterior by means of the numerous stomata on the lower epidermis This loose tissue forms the spongy parenchyma concerned with the exchange of gases between the atmosphere and the living cells. All the epidermal cells are colourless except the guard-cells; every here and there they give rise to stiff multicellular hairs.

The differentiation of the tissues of the leaf which has just been described is characteristic of plants which bear their leaves horizontally, and so secure brighter illumination for the upper surface than for the lower. The upper part of the leaf becomes naturally the chief assimilating region, and the cells are closely packed that no space may be lost. The purpose of the long shape of the cells is not so obvious, but it is probably also connected, though in a different way, with the peculiar sensitiveness of chlorophyll to light. While unable to perform its proper work for the plant in darkness, it is nevertheless easily injured by excessive illumination. Now the protoplasm in these long cells readily reacts to variations in the intensity of light, and in direct and brilliant sunlight moves in the cell in such a manner as to place all the little discoid chloroplasts upon the long walls that run at right angles to the surface so that their edges only are exposed to the light. In diffused daylight they are found, however, chiefly in the upper and lower walls and face upwards. The under side of the leaf will never be too brightly illuminated, and no such contrivance is found there.

The problem as to what causes the sap to rise from beneath the ground to the top of the plant has already been referred to, and may be dealt with at more length here. The difficulty will be appreciated from the following figures. Experiment shows that, under ordinary circumstances, a foliage leaf may give off from 1 to 10 c.c. of water

from every square centimetre of its surface in twenty-four hours. A single large tree may transpire from the whole sum of its leaves as much as 400 kilogrammes in the same time. This means that every day a corresponding mass of water must be raised from the roots to the leaves, or obviously the latter would wither. We know the channel through which the current of water passes, but at present we know of no sufficient cause for the *upward* flow. The rapidity of transpiration itself doubtless helps (see p 189), but its influence cannot be felt except in the immediate neighbourhood of the leaves themselves To a considerable extent it seems that water is actually forced up from below. If a vine is pruned in the spring, just as the young leaves are unfolding, sap will exude from the wound, and bleeding, as it is called, may continue for days, yet here there are no leaves above to cause a transpiration current. When a curved tube filled with mercury (Fig 98) is fitted over the cut end of the vine stem, the pressure of the exuding sap may be sufficient to raise the level of the column of mercury to a height of 850 millimetres, or slightly more; it would therefore be sufficient to raise a column of watery solution of salts between 11 and 12 metres. This follows simply from the relative density of the sap as compared with mercury. Some considerable force is at work here, and it has been given the name of root-pressure, but we know very little of its real cause. Probably it arises from peculiar

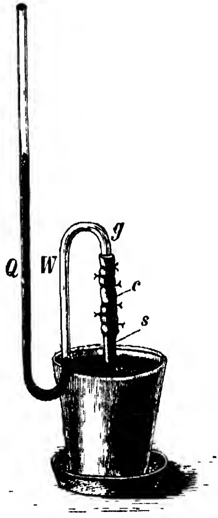


FIG 98. Experiment to illustrate root-pressure. (From Jost)

c rubber tubing
g glass tube
Q mercury
s cut end of stem.
W water forced out of stem

conditions of turgidity in the cells around the vascular bundles in the young parts of the root, so that the liquid which is absorbed by the root-hairs and passes by osmosis though the substance of the ground-tissue is at last forced under considerable pressure into the vessels of the xylem. In herbaceous plants and shrubs it is possible that root-pressure and transpiration together may be able to maintain the upward flow of sap; in large trees, however, they are obviously insufficient, and for the present we can only acknowledge our ignorance.

It is in the structure of its reproductive organs that Helianthus differs most markedly from Pinus, and these will now be described. Each so-called flower, which is in reality a very complex flower-head, is borne on the thick flattened apex of the main stem, or one of its branches, and is surrounded by several closely set rows of specially modified leaves, which are known as the involucre. This folds over and completely covers the flower-head and serves as a protection while it is still in bud. When the sunflower opens a marked distinction is at once noticeable between the outer yellow rays and the flattened middle of the head, which closer examination shows to be made up of a number of separate tubular flowers, known as the disc florets. Round the rim the florets are of a different shape and are known as ray florets.

The tube or corolla of each disc floret ends above in five little pointed teeth. Inside the tube and attached to it by five stalks are five structures known as stamens, which, from the fact that when ripe they shed pollen, may readily be identified as corresponding to the scale bearing microsporangia in the pine Each stamen consists of a stalk or filament, which is attached at its base to the wall of the tube, and a long narrow bilobed head or anther, up the back of which passes a continuation of the filament, here known as the connective. This contains a vascular bundle to carry nourishment. The anthers are long and flattened, and are all fastened together so that they form a kind of inner tube. In the middle a straight rod can be seen which, in a well-opened flower, spreads out at the top above the stamens, in two horizontal projections. The upper surface of these horizontal portions

is covered with sticky papillae, and forms the stigma; the long rod is called the style. If it be traced downwards it will be found to be attached at the bottom of the tube to a little somewhat oval flattened body, from the wide upper end of which the corolla itself appears to spring. This body is the ovary, and contains within it, completely enclosed as in a box, a single ovule. Outside the corolla, and also apparently springing from the top of the ovary, are two little green scale leaves which represent the so-called calyx.

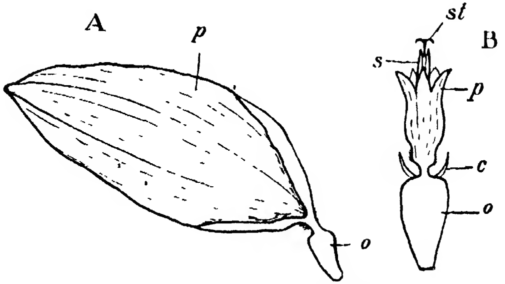


FIG 99 A Ray floret. B. Disc floret.

c. calyx. *p* corolla *st.* stigma
o. ovary. *s* stamens

Among the chief differences revealed by a simple naked-eye examination between the flowers just described and the cones of the pine the following points may be specially noted. the megasporangia or ovules are no longer exposed on the surface of a scale but are completely enclosed in cases known as ovaries. The microsporangia are clustered together to form definite anthers supported by clearly differentiated filaments; there is no differentiated scale which bears them. The microsporangia and megasporangia are borne close together in the same flower. specially modified floral leaves are developed in connexion with the sporangia for purposes of protection, and obviously, from their bright colouring, for other purposes also. This

last point is most obvious in the ray florets to which we now turn

Each long narrow yellow ray is continued downwards to form a tiny tube, and, from its appearance at the base, it can readily be identified as corresponding to the more protective, but less ornamental, corolla tube of the disc florets. No stamens, style, or stigma are present. There is a rudimentary ovary at the base, but seeds are never formed. These florets, indeed, are merely for show, and play no direct part in the processes of reproduction.

The formation and development of the spores must now be described. Each anther is at first a mere mass of undifferentiated tissue, except for the vascular bundle of the connective which runs through the midst of it. Then four rows of cells below the surface, in positions shown in cross-section in Fig. 100, become distinguished from the rest by their size and activity. Each gives rise to a mass of spore mother-cells, each of which in its turn divides into four spores. There are, then, at this stage, four well-developed microsporangia (pollen sacs) filled with spores. Presently the walls between the two adjacent microsporangia of each side break down, and the spores lie freely in two large spaces. Ultimately each lobe splits along its whole length, and the ripe pollen-grains are shed. As in Pinus, each microspore begins to germinate before it leaves the microsporangium, here, too, only a single division of the nucleus takes place When set free, each pollen-grain is a very rudimentary prothallus surrounded by two coats, the inner one fine and thin, the outer thicker, more protective. The air-sacs described in the pollen-grain of Pinus are not formed, the grain is more or less round, with a roughened exterior.

The megasporangium appears as a little mass of undifferentiated tissue at the base of the ovary. As it grows it becomes almost covered by an integument formed as an upgrowth from its base, and curves in such a way that the micropylar opening faces downward, close to the stalk by which the sporangium is attached to the bottom of the ovary A single large megaspore (embryo sac) develops in the megasporangium, and begins to germinate far more rapidly than in Pinus, but fewer cells are formed as the result of its division. When the

first division is complete the daughter-nuclei travel one to each end of the embryo sac. There each divides, and the products divide again. One nucleus from each end then travels back to the middle, and at some time or other the two nuclei which thus meet fuse together to form the so-called definitive nucleus or primary endosperm

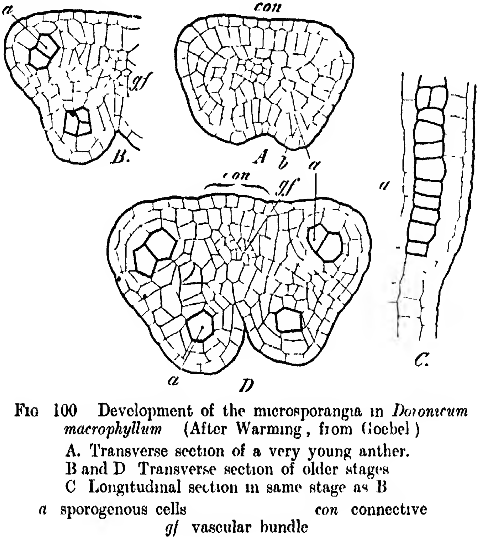


FIG 100 Development of the microsporangia in *Doronicum macrophyllum* (After Warming, from Goebel)
A. Transverse section of a very young anther.
B and D Transverse section of older stages
C Longitudinal section in same stage as B
a sporogenous cells *con* connective
gf vascular bundle

nucleus. Obviously all the divisions so far described represent a very rudimentary formation of prothallus or endosperm. Three cells are now left at each end of the embryo sac Those at the micropylar end form the egg-apparatus, and possibly each cell is a potential ovum, though only one is actually fertilized; the three cells at the other end are known as the antipodal cells, and in the sunflower they undergo some little further development, and probably help in the nutrition of the embryo

sac. The ovum is now ready for fertilization, but, being enclosed with the prothallus within the megasporangium, and this, in its turn, being shut within the ovary, it is obvious that the pollen-grain can obtain no near access to it; provision is, however, made for this situation, and the pollen-grain is caught on the sticky surface of the stigmas. There it continues to grow, as does the pollen-grain of Pinus when it rests on the nucellus of the ovule, only here growth is much quicker, and the pollen-tube, which is formed from the delicate inner coat of the grain, is so long that it penetrates the whole length of the style, and at last reaches the micropyle and passes through the substance of the sporangium. At first it is only the vegetative nucleus concerned in the actual growth of the tube which passes down into it as it elongates. Then the other nucleus divides into two, and both the daughter-nuclei travel down also. These latter are the generative nuclei. One of them passes through the end of the pollen-tube and fertilizes the ovum; the other usually follows and fuses with the definitive nucleus in the middle of the embryo sac. It is difficult to see the exact meaning of this latter fusion. So far as we know, it corresponds to nothing in the lower plants, and it cannot be regarded as a part of the actual reproductive process. It has been suggested that its purpose may be the stimulation of the definitive nucleus to fresh activity, and certainly rapid cell-division follows the union. A mass of tissue is thus formed which is probably to be regarded as a further late development of prothallus or endosperm. The deferring of any great formation of endosperm till after fertilization has taken place must be looked upon as a special adaptation for purposes of economy Did the ovum miss being fertilized there would be no need for endosperm to feed the growing embryo. Hence, the curiously early differentiation of the ovum, and the specialization of the definitive nucleus with its latent powers of growth.

Growth of the embryo keeps pace at first with growth of the endosperm; then the embryo begins to feed on the tissue surrounding it, and before the seed is ripe both endosperm and nucellus are completely used up. The young plant fills the whole integument of the ovule, and the latter is pressed closely against the now hardened wall of the ovary.

The reserve food material which must be present for the early stages of germination is stored in two large thick cotyledons or seed-leaves, which fill almost the whole of the seed-case. A well-developed radicle points downwards towards the position of the micropyle, which can no longer be distinguished in the very delicate skin covering the seed. A minute baby shoot, or plumule, is barely visible just above the radicle between the two cotyledons.

In germination the radicle grows first, at the expense of the food in the cotyledons, and breaks the hard wall of the ovary. A region immediately below the cotyledons elongates rapidly, becomes curved, and forces its way up above the soil (cf. fern fronds, p. 200), while the delicate tip of the root pushes downwards The seed-leaves, now made thin by the withdrawal of their stores, are raised above the ground The seed-case drops off, the cotyledons spread out to the light and air, become green, and perform all the work of ordinary foliage leaves for a considerable time before the plumule develops.

The life-history is now complete and may be represented by the following table :—

Sunflower-plant (Sporophyte)

Microsporangium (pollen sac)	Megasporangium (nucellus)
Microspore (Gametophyte) (pollen-grain)	Megaspore (Gametophyte) (embryo sac)
Prothallus	Prothallus (endosperm)
Generative Cell	Ovum

Oospore (Sporophyte)

Embryo.

The description given above of the main features of the development of the two kinds of spores, their germination, the union of the gametes, and development of the embryo, is applicable with but slight modification to any plant whose ovules are enclosed in an ovary. In some, as in the castor-oil seed, the endosperm is persistent; in others

it is all used up, and the food is stored in the cotyledons; in one great group of these plants only one cotyledon is formed, in all the rest the embryo is always provided with two. The origin of the megaspore, the small size of the prothallus, its late development, and the fertilization of the ovum, are, however, extraordinarily constant, even down to points of minute detail, in all these plants.

It remains to describe certain features which are characteristic of the sunflower, though other flowers have more or less similar contrivances for the same ends. The near neighbourhood of microsporangia and megasporangia would seem to make it probable that an ovule would get fertilized by pollen from its own flower, which apparently is not advantageous, for all sorts of devices are found to prevent self-pollination. In this case, when the stamens are ripe and shedding their pollen freely down the middle of the tube, the stigmatic surfaces are pressed closely together (Fig. 101, I), and the pollen shower falls on the hairy outer surface of the style, where it sticks, but is unable to germinate. Later the style begins to grow, pushing its way up through the tube and acting like a brush to clear the pollen out. Presently it may be seen projecting up above the stamens with a yellow mass of pollen clinging around its tip (Fig. 101, II). Most of this falls away as the forks of the style unfold, some may remain clinging about the upper part of the style, but none can get on the stigmatic surface, where alone it can be of any use. At this stage the stamens, which have hitherto projected considerably above the corolla, are partially withdrawn within the flower by a curious bending of the filaments (Fig. 101, III); the unfolded stigmas come to occupy the place where the tips of the anthers had been, and are now the most projecting part of the flower.

Now obviously in the sunflower there is no adaptation for the pollen to be carried by the wind, but the bright colour, and probably the scent of the flower-head, attract insects, and here, it may be noticed, comes in the use of the showy but sterile ray florets. Honey is secreted by the basal portion of the style (Fig 101, *h.g.*), in the disc florets, and this can only be reached by insects with fairly long tongues, as bees and some flies. As these walk over the surface of the flower-head the under side of their bodies will

be brushed by the projecting mass of pollen in the younger flowers towards the centre of the head. Towards the edge the florets are further developed, and in the older stages, as already seen, the stigmas are the most projecting part of the flower. These, then, will brush against the bee's body and in so doing they are almost certain to have

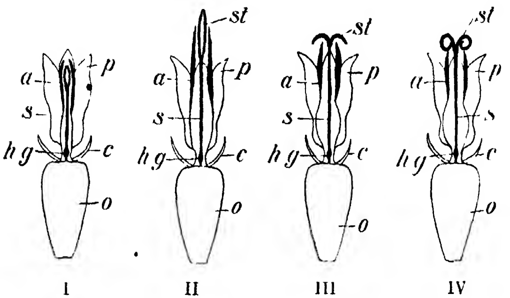


FIG 101. Stages in the development of the disc floret of *Helianthus annuus*

I The stamens have just begun to shed their pollen
II The stamens have lengthened and project above the corolla. The style has also lengthened and carries a little mass of pollen above the opening of the anther-tube
III The anther-tube is shortened by the bending of the filaments. The stigmas have spread open
IV The stamens are still further shortened and the stigmatic surfaces are curled round to pick up pollen

a anther *p* corolla.
c calyx *s* style
h g honey gland *st* stigmatic surface
o ovary.

pollen from another floret deposited upon them, and thus cross-pollination is effected. By these elaborate contrivances great economy of the pollen is secured; the chances of waste are very much less than in the pine and a comparatively small quantity of pollen need be formed. A possibility still remains, however, that a given flower may not be visited by an insect at the right time. Even so, the formation of the seed may still take place. As

the flower begins to die, and just before the stigmas shrivel, the latter may be seen to curve backwards and begin gradually to roll themselves up into two little spirals. This looks like a mere contortion due to withering, but in reality the sticky surface of each stigma is by this means brought against the upper part of the stamen-tube and the hairy surface of the style, to both of which some few pollen-grains still cling Grains from another flower are better, but if they cannot be obtained self-pollination may result in seed formation

Pinus and Helianthus resemble each other and differ from all the other plants described in the extraordinary reduction and dependence of the gametophyte generation. Not only do both kinds of prothalli obtain their whole sustenance from the sporophyte, but that derived from the megaspore lives its whole life, and even produces its offspring, while still enclosed within the sporangium and attached to the parent plant. The resulting structure, consisting essentially of the baby sporophyte, with or without remnants of the parent gametophyte and covered by the seed coats, is known as a seed. It is the characteristic product of a flower, and forms the distinguishing mark of the flowering plants, or Phanerogams. The most ancient group is undoubtedly that which has been represented here by Pinus. The megasporangia are borne naked on the surface of a sporophyll or scale, and consequently these plants have been given the name of Gymnosperms, to distinguish them from the Angiosperms (e.g. sunflower), in which the megasporangia are completely enclosed in ovaries. All living Gymnosperms are trees, but in past geological ages a far greater variety of kindred plants flourished on the earth. Once they were the dominant group, now they yield to the more highly developed Angiosperms, which seem to have become adapted to fill an almost infinite variety of places in the economy of nature Within the group two great classes can be distinguished. One, to which belong most of our early spring bulbous plants, the tulip, snowdrop, narcissus, and many others, as well as the grasses and the grains, like the corn and maize, is characterized by the development of a single cotyledon in the seed, and hence the whole class of

plants is known as the Monocotyledons. They are distinguished by certain other structural peculiarities also from the other class or Dicotyledons. The most important of these is that their vascular bundles are scattered irregularly through the stem, instead of being grouped together in a circle, while the usual absence of cambium makes secondary thickening generally impossible even in the tree forms; this, however, is of no disadvantage to the tree, for the Monocotyledons do not show the yearly increase of leaf surface which is so characteristic of dicotyledonous trees like the lime or the chestnut.

In the series of plants described in the last few chapters it has been pointed out in each case that, strictly speaking, a plant does not resemble its parent, but its grandparent, for unlike generations regularly alternate with each other. Before the life-history of these plants was known or understood, it had been observed that in certain animals the offspring is dissimilar from the parent, for between two like forms of different generations there may be intercalated one or more generations of individuals of another kind. Further, it was noted in these animals that if one generation forms gametes the next reproduces in some other way, but finally gives rise again to gamete-bearing individuals. Such an alternation of generations was first recognized at the end of the eighteenth century, and was later worked out in detail for the hydroid colonies such as Obelia (p. 73). Here the medusa was regarded as the 'perfect' individual, because it produces gametes. The offspring, however, is not another medusa, but a hydranth, which, by a different kind of reproduction, now known to be budding, gives rise to a number of other polyps like itself, finally medusae again arise (see p 78). A similar kind of multiplication of individuals between two consecutive generations of 'perfect' animals was noticed also in some of the worms (see p 102)

The ideas obtained from a study of hydroid colonies and other forms were not difficult to apply to plants. The stamens and pistils of the flower were regarded as the 'perfect' individuals. The seed formed from them gave rise to a different kind of individual, the vegetative part of the plant, which reproduced itself to form a

branching colony in the same sort of way as the original hydranth does. Ultimately, by the same process of budding, 'perfect' individuals were again formed.

As knowledge of the reproductive processes of plants grew more detailed and complete, it gradually became clear that a distinction should be drawn between the vegetative multiplication by buds and true reproduction, whether by spores or gametes; and, further, that, quite apart from the vegetative multiplication which is universal in plants, though comparatively rare among animals, there is a regular alternation of spore-bearing and gamete-bearing individuals among the majority of plant forms. This is a kind of alternation which finds no parallel among animals except in some Arthropods and a few other forms (see liver-fluke, p. 104). The term alternation of generations thus came to cover a number of very diverse phenomena, but it is now limited by Botanists to the regular alternation of sporophyte with gametophyte, while Zoologists use it in the older, wider sense.

The introduction of the sporophyte generation into the life-history of plants must probably be understood as an adaptation to the conditions of life on dry land, while its non-occurrence in animals is most likely to be regarded as connected with their power of locomotion. Water is the ancient home of all life, and to the present day we find that the simplest forms both of animals and plants are aquatic. The union of the gametes, to which the fixed life of the plants would otherwise oppose a serious obstacle, is therefore effected in primitive forms by one or both of the gametes themselves being motile. These ciliate or flagellate gametes are still characteristic of simple green land plants (see moss and fern), and restrict the gametophyte to a low-growing habit and to situations where abundant moisture can be obtained at the right time The development of the sporophyte, which appears at first as a simple stalked sporangium, marked a great advance in that it facilitated dispersal and allowed of a rapid multiplication of gametophytes without the presence of water being essential. In the fern the sporophyte is set free from its dependence on the gametophyte by the development of absorbing and assimilating organs of its own, an arrangement which proves a more perfect

adaptation to land conditions, as seen in the greater specialization of the fern as compared with the moss. It is, however, only in the flowering plants, with their great specialization of sporophyte and correlated reduction of the gametophyte, that the adaptation becomes perfect, and a new means of transmission of the gametes wholly suited to land conditions is at last attained.

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